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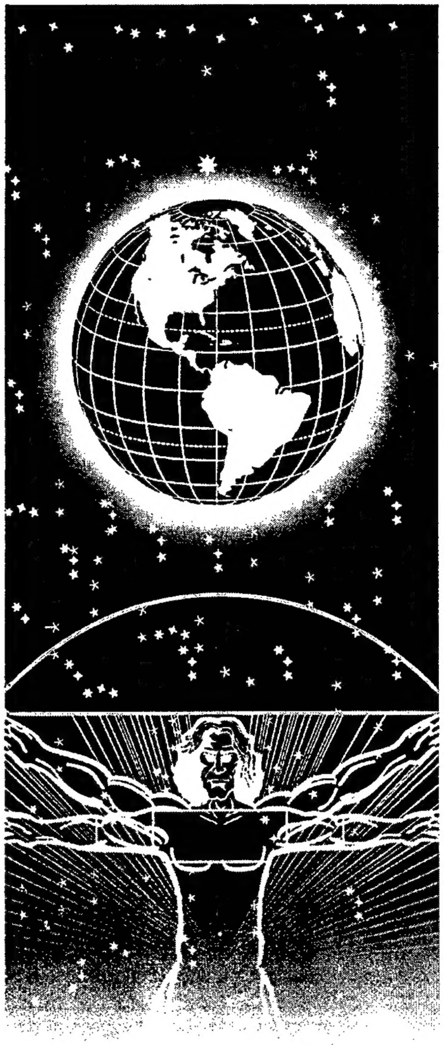

UNITED STATES AIR FORCE RESEARCH LABORATORY

SYNTHETIC TASK DESIGN: COGNITIVE TASK ANALYSIS OF AWACS WEAPONS DIRECTOR TEAMS

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14. ABSTRACT

In this report, we describe a cognitive task analysis (CTA) of Airborne Warning and Control Systems (AWACS) Weapons Director teams. We used three different CTA techniques to investigate how Weapons Directors typically perceive, decide, and act with respect to their environment. The results of the CTA were then distilled to provide both a description of the AWACS job and some preliminary specifications for designing the SynTEAM (Synthetic Team Effectiveness Assessment and Modeling) task. SynTEAM is a synthetic team-task environment based on the AWACS. SynTEAM will ultimately be used in laboratory studies aimed at investigating the characteristics of team behavior and cognition.

15. SUBJECT TERMS

Airborne Warning and Control System; AWACS; Cognitive Task Analysis; Command and Control; Synthetic Task; Teams; Team Training; Weapons Directors

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PREFACE

This research was funded by an Air Force New World Vistas grant from the Air Force Office of Scientific Research, awarded to Drs. Ellen Hall and Wes Regian (Work unit 2313HM10). The authors would like to thank: Drs. Ellen Hall, Lee Gugerty, and Renée Zakia for their conceptual input; Mr. Matt Dalrymple and Capt. John Kenny for their technical expertise and extensive assistance; Drs. Sam Schiflett, Linda Elliott, Mr. Jeff Whitmore and the staff at the AESOP facility for their time and assistance; Capts. Steven Jones and Dave Ashton for orchestrating facilities and personnel for our data collection trip at Tinker AFB, and finally all the AWACS Weapons Directors, who served as interviewees for this project. Scott Chaiken provided editorial assistance on the final version.

INTRODUCTION

Although many complex systems are operated by teams rather than by single operators, the cognitive and behavioral processes driving effective team performance in dynamic, real-world settings are not well understood (Regian & Elliott, 1997). To address this shortcoming, the Air Force initiated the New World Vistas (NWV) Cognitive Engineering for Teams program. Central to this program is the development of a number of synthetic team task environments (STTEs), defined as computer-based artificial team tasks designed specifically for basic research purposes, yet modeled after real world tasks. These STTEs will ultimately be used in laboratory studies aimed at investigating the characteristics of team behavior and cognition. As such, STTEs will offer a number of advantages over the use of both conventional simulators and existing artificial tasks:

- Unlike participants in simulator studies, participants in studies using STTEs will not have to be domain experts. STTEs will be simple enough that naïve subjects will be able to become task-proficient in a matter of hours.
- Unlike simulators, STTEs will be reconfigurable: researchers will have the flexibility to systematically manipulate important task characteristics and collect data reflecting the effects of these manipulations.
- Unlike many existing artificial tasks, STTEs will be *ecologically valid*: that is, care will be taken to ensure that conclusions drawn from studies performed using STTEs will also apply to the real world task on which the STTE is modeled.

However, building an STTE is not simply a matter of choosing a real world task and producing a simplified version of it. While STTEs certainly need to be simpler than their analogous real world tasks, the value of the STTE as a research vehicle depends heavily on the way in which simplification is achieved. The purpose of an STTE is to allow investigation of task characteristics that drive task performance in the real world, so it is important that critical real world task characteristics be preserved in STTEs.

To achieve this, one must:

- Determine the important characteristics of the real world task: the major features and goals of the task, the subtasks that enable the goals to be attained, the decisions and problems facing performers of the task, and the cues and information used to support decision-making and problem solving
- Build the STTE to share these characteristics

For example, if a major concern for Air Traffic Controllers (ATCs) is scheduling runway space for flights arriving simultaneously, then an STTE based on the ATC task should require subjects to solve similar scheduling problems, using similar cues and information. Conversely, there may be characteristics of the real world task that, although superficially striking, are not important determinants of performance and so should not be preserved in an STTE. For example, once a runway schedule has been made, real world

ATCs may have to pass it on to other personnel by executing a number of console operations. Although these operations may appear complex, controllers may carry them out with little effort due to such procedures being highly learned. However, if the STTE were designed such that passing on the runway schedule also required performance of a complex set of operations, STTE subjects would have difficulty performing this operation, possibly making errors that have no real world counterparts. Therefore, the goal should be to simplify complex operations such that each STTE operation makes the same relative demand of STTE subjects as the analogous real world operation does of real world operators.

Cognitive Task Analysis (CTA) methods are used to analyze the performance of tasks that have large cognitive components: that is, when task performance is highly dependent on mental processes. CTA methods go beyond traditional task analysis approaches, aiming to describe characteristics of tasks such as workload, decision-making strategies, and errors. It is this focus that makes CTA ideal for guiding STTE design: knowing the cognitive characteristics of a real world task, an STTE can be designed to have the same cognitive characteristics, yet be behaviorally much simpler. Accordingly, the NWV program has funded our group to perform CTAs in the service of STTE development, simultaneously advancing CTA methods to cope with dynamic, real-time team tasks. In this report, we present the results of a CTA of the AWACS Weapons Director task. The Weapons Director task is the real world counterpart of "SynTEAM" (Synthetic Team Effectiveness Assessment and Modeling), an STTE in development.

Domain Overview

The E3 Airborne Warning and Control Systems (AWACS) aircraft carries both surveillance personnel and Weapons Director (WD) teams. WDs are responsible for the command and control of aircraft within a particular area. In an existing cognitive task analysis of AWACS WDs, Klinger, Andriole, Militello, Adelman, and Klein (1993) describe the WD task:

> "The WD position can be likened to that of an Air Traffic Controller in the sky, with some important differences: commercial aircraft seldom shoot at one another, the Air Traffic Controller never needs to monitor an airborne track in order to determine intent; Air Traffic Controllers are seldom in danger of being shot down (they are not flying in the sky with the aircraft they are controlling); and they do not need to worry about rules of engagement. A WD must contend with all of these and more." (p. 3)

Another important difference between Air Traffic Controllers and WDs is that WDs are primarily concerned with directing aircraft toward each other, as in the case of orchestrating an intercept or an aerial refueling, rather than exclusively trying to keep aircraft apart[1]. Performing this task requires great precision and attention, and guiding

[1] Although WDs also do this: they "deconflict" aircraft so they don't inadvertently fly into one another.

aircraft towards one another makes great perceptual demands on the operator, more so than keeping separation between aircraft or directing an aircraft to a stationary runway on the ground. A small mistake on the part of a WD could make the difference between making a successful intercept and allowing a hostile plane to penetrate friendly airspace. Further, WDs have to contend with different mission objectives: for example, a mission might involve patrolling a quiet airspace, reconnaissance, launching a defensive counter air strike in response to an enemy attack, or controlling an offensive strike package penetrating into enemy territory, as well as non-combat missions such as search-and-rescue. To add further complications, within a given mission WDs have to perform a range of different tasks, such as monitoring aircraft launches and landings, monitoring enemy aircraft, running intercepts (executed in different ways depending on the current rules of engagement and/or the relative strengths of the aircraft involved), overseeing rescue missions for downed pilots, and mid-air refueling of aircraft. Performing these tasks requires tracking an enormous amount of information, such as the position, heading, altitude, and speed of both friendly and hostile aircraft, and the fuel and armament status of friendly aircraft, as well as maintaining awareness of the current Rules of Engagement (ROE). Contending with all this information, WDs have to manage the deployment of their often-limited assets to deal effectively with all that is going on in their airspace, or Area of Responsibility (AOR). In such a highly dynamic and fast-paced environment, this is an extremely challenging task.

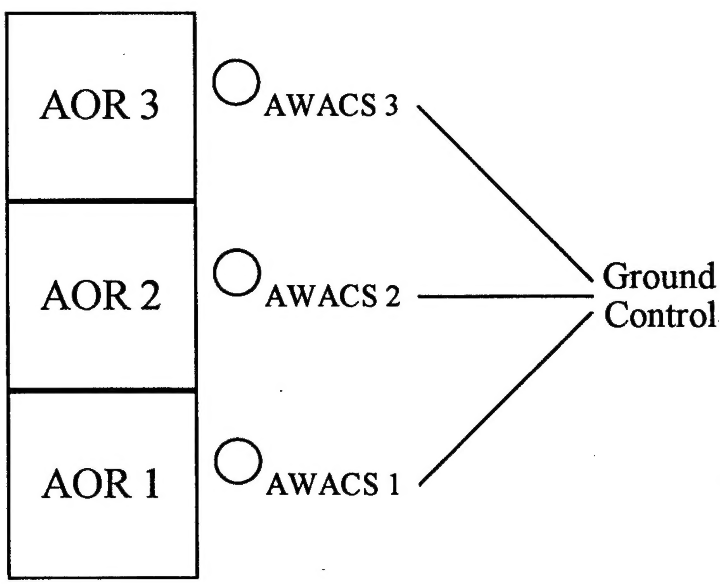

Figure 1: Illustration of how multiple AWACS aircraft work in tandem

The workload involved in directing a whole mission is clearly too much for one person, and that is why WDs work in teams. Team size varies according to the projected demands of the mission. A typical set-up for a routine patrol mission will have 3 WDs, while a more involved strike mission might have 6 WDs. On the AWACS aircraft, WDs sit at individual consoles arranged in rows of three. Within a team, each WD takes on different responsibilities. Responsibilities might be divided according to geography, with each WD controlling operations in a different portion of the airspace (or "lane"), or

according to function, with each WD responsible for different functions (such as control of airborne tankers and refueling operations, responsibility for aircraft check-in, or control of a strike package) within the total AOR. For missions involving a large number of forces to be controlled, two or more WDs might be assigned to one functional role: for example, in a mission involving a large strike force there may be a main strike controller and one or two "assist" controllers. Currently, the functional division of labor is far more common. In situations in which there is a large quantity of airspace to be controlled, or when it is advantageous to divide the airspace into discrete regions, a number of separate AWACS aircraft might be used, each having on board their own team of WDs responsible for their own AOR, and each answerable to Ground Control (Figure 1).

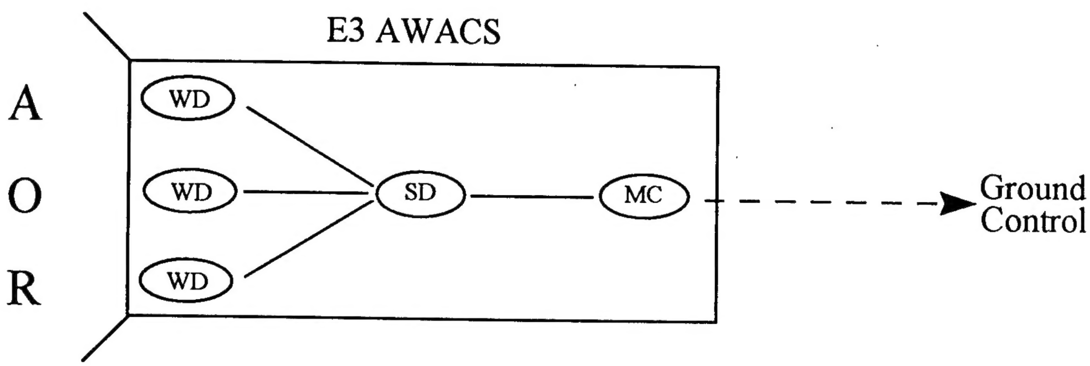

Figure 2: Illustration of the chain of command on a single AWACS aircraft

Each WD team falls under the leadership of a Senior Director (SD), who sits at a console located behind those of the WDs. SDs are qualified WDs who have received extra training, but who are not necessarily more experienced than the WDs on their teams since only officers can be SDs. The SD monitors the WD team, facilitating coordination between WDs and generally making sure that the mission stays on track. SDs often use a "Socratic method" to ensure that WDs maintain their situation awareness. For example, the question "what is that in the North-West corner of your lane?" might not really be a request for information, but a reminder to the WD that there is an unnoticed hostile coming into the lane that needs to be dealt with. WDs often face decisions that are outside their authority (in fact, most decisions at the strategic level are beyond WDs' authority). WDs work through these decisions with their SD, who can act autonomously or confer with the chain of command (i.e. the Mission Commander [MC] and then Ground Control as shown in Figure 2).

All WDs, and the SD, sit at identical consoles consisting of a radar screen ("scope"), a trackball, an alphanumeric keyboard, a number of specialized switch panels, and a radio. WDs receive information from both their scope and the radio, and experienced WDs place roughly equal weight on both sources. The main feature of the scope is a graphical display of the AOR, showing data from AWACS radar returns superimposed over an outline map of the ground territory. The map shows basic information such as land/sea borders, international borders, cities, airfields, and missile sites.

The radar provides the current positions, headings, altitudes, and speeds of aircraft in the AOR, as well as any identification modes and codes that aircraft are transmitting ("squawking"). Radar returns are known as "tracks". Track information is updated with every radar sweep, or every 12 seconds. However, not all of the available information is usually displayed at once, depending on which options each WD has chosen in setting up his[2] scope. Typically, the system displays current track positions as dots, with headings signified by the direction of short lines originating at each dot, and track "histories" displayed as a series of blinking dots showing each track's position at the last three radar sweeps (i.e. the last 36 seconds). The histories provide WDs with a representation of aircraft movement, making it easier to see when tracks change heading. The color of the dot conveys information about the identification modes and codes that the aircraft is transmitting. A green dot means that the aircraft is transmitting an identifiable code (and so, barring any counter-measures, is probably a "friendly"), a yellow dot means that it is not transmitting identifiable codes (and so is probably not a friendly).

Tracks are further identified by "tagging" them with a symbol and track number, or "symbology". The symbology identifies the aircraft as a bogey (unknown), bandit (identified enemy), or friendly. WDs are typically responsible for identifying and tagging friendly aircraft (those transmitting identifiable codes), while identification of unknown aircraft is usually done by the surveillance team, also working from the AWACS aircraft.

WDs also use their consoles to record and keep track of mission progress. For example, when a command is issued to an aircraft, it should ideally be reflected by an input to the system, usually achieved via one of the 80 "switch actions" located on a panel to the right of each scope. Completed switch actions are propagated through the whole system and are reflected in the symbology and information available at each console. Thus if a WD sends a fighter to intercept a hostile aircraft, this should be reflected with a "commit" switch action, and the aircraft's commit status is shown as part of its symbology. Since this information is available to all the other WDs (as well as the SD, the MC, and Ground Control, all of who may be looking at an AWACS radar screen), it is important that the system be kept current.

Of the 80 switch actions at a WD's disposal, some are intended for communication with the AWACS system, some determine display characteristics for individual scopes (such as zoom and declutter functions), while others activate tools to aid WDs in decision making, such as tools to calculate intercept geometry. Information not displayed on the map display can also be displayed numerically as a tabular display (TD). TDs are usually displayed on the scope just below the map, although it is possible to display full-screen TDs and toggle between these and the map display. Each WD is free to set his display options independently, so although all WDs have access to the same information their individual scopes may look very different at any given time.

[2] Throughout this report we have used male pronouns to refer to WDs and pilots, as there are no gender-neutral alternatives that do not render the text awkward.

As for the radio, the channels on all WDs' radios are tuned to receive the same frequencies. The Guard channel is an international frequency used for general purpose and emergency communication between aircraft. Four intercom channels, known as Net 1 (flight deck), Net 2 (WDs and SD), Net 3 (surveillance), and Maintenance, are used for internal communication aboard the AWACS aircraft itself. WDs sometimes talk about "Net 4", but this is merely WD jargon for face-to-face verbal communication.

The remaining four channels, known as A, B, C, and D, are used for communicating with other aircraft. The frequencies of these channels are changed for each mission. Although each WDs' radio is tuned to the same four mission frequencies, the frequencies are configured differently on each radio. Each WD's radio is configured such that the aircraft with which he is most likely to communicate are broadcasting on his "A" channel. For example, a WD controlling patrol fighters would be able to communicate with all of his fighters on Channel A. For the WD controlling tankers in the same mission, Channel A would be tuned to a different frequency, on which tankers would communicate. However, the WD controlling the fighters would also be able to communicate with the tankers, since either his B, C, or D channel would be tuned to receive the tanker frequency. A WD controlling aircraft check-in would receive a special check-in frequency on Channel A, on which all aircraft broadcast as they take off. The WDs controlling fighters and tankers would have access to this frequency on their Channels B, C, or D, while the WD performing check-in duties would be able to access the fighter and tanker frequencies on his other channels. It is possible for a WD to pass control of an aircraft to another WD, and when this is done the pilot is "pushed" to the new WD's Channel A frequency.

WDs can listen to any combination of frequencies at one time. They control which of the channels they hear by adjusting the volumes: a common listening strategy is to turn up the volume on the most relevant channels (typically Channel A, Net 2, and Guard) and modulate the volume on all others, listening to some at a reduced volume and turning others off completely. To speak over a particular channel, the WD pulls out the button for that channel, then presses on a pedal while he talks. It is possible to talk on more than one channel at one time by pulling out more than one button.

Using the console, WDs communicate with their pilots, and among themselves, to successfully complete a range of different types of missions in which many different kinds of unexpected event might occur. However, WDs do this with almost no training in teamwork or team interaction. Prior to being certified "mission ready"; the only experience a WD has had with a team is simulator practice, with no overt instruction on teamwork.

For a typical mission, WDs start with a comprehensive briefing. Briefings may last a number of hours, and during this time, WDs review the mission objectives, the schedule of aircraft that will be flying, known as the Air Tasking Order (ATO), and the Rules of Engagement (ROE), which define how aircraft should behave in case of contact with unknown or enemy aircraft. The ROE are liable to change during a mission (e.g., aircraft may be put on a higher state of alert), and WDs discuss this possibility and how they will

deal with it. WDs' roles and responsibilities are clearly defined during the briefing, dictating how they will communicate and coordinate, and WDs work out among themselves how they will communicate and coordinate with each other in special circumstances by way of verbal "contracts". Most missions that WDs fly are routine and uneventful, with aircraft flying more or less according to the ATO. These types of mission pose very few problems for WDs. When non-scheduled and unexpected events occur, such as encounters with enemy aircraft, the WD task becomes very challenging, and teamwork becomes critical, as WDs become more overloaded and events deviate further from a priori plans.

This Study

Our goal in this study is to describe the important characteristics of the WD team task and to provide preliminary specifications for SynTEAM design. To achieve this, we used a number of different interviewing methods that converge on a common task description. "General" interviews were semi-structured interviews using questions derived from the researchers' initial domain analyses using documentation, videotapes, and informal discussions with a subject matter expert (SME). The purpose of the general interviews was to elicit broad, context-free knowledge and information about the WD task in order to better guide the more detailed analyses planned for the future, and also to capture the stable domain knowledge underlying task performance. "Critical incident" interviews (Klein, Calderwood, & MacGregor, 1989) were usually conducted in the same session as general interviews, and were used to sample real decisions, procedures and strategies that underlie actual task performance. Finally, "quasi-performance" interviews used an adaptation of PARI (Hall, Gott, and Pokorny, 1995) in order to elicit detailed task knowledge. The main strength of performance interviews is that knowledge is elicited in the context of actual task performance, either real or simulated, thus targeting "knowledge in action". While critical incident interviews can also yield detailed information elicited in the context of task performance, performance interviews have a number of unique features:

- Data are collected in the context of a full array of environmental cues, providing the interviewee with ecologically-valid "prompts". Data are thus be more complete than data collected retrospectively, minimizing the chance of missing important information due to failures of memory.
- Since the researcher is present during task performance, he/she can probe the interviewee about aspects of task performance that may be interesting from the interviewer's point of view but that could be glossed over or omitted completely if interviewees were left to their own devices. This feature helps combat the well-known knowledge elicitation problem of experts being unable to verbalize their expertise.
- Since data are collected in the context of prefabricated scenarios, the variety of data is limited by the creativity of those designing the scenarios. This "limitation" can provide an advantage. Careful scenario design (incorporating input from SMEs) can produce a wide variety of challenging and realistic events. Further, scenario design allows

researchers to play an active role in guiding the data collection. For example, being interested in teamwork, researchers could design scenarios for which team interactions are a critical part of mission execution. Other methods of elicitation depend on the interviewee's prior experience (e.g. the critical incident method), which may or may not include target concepts (e.g. teamwork) as important factors.

- The use of a limited number of standard scenarios allows for direct comparison of data across subjects: for example, one could compare data from experts and novices confronted with the same scenario.
- Since interviewees are called upon to make decisions in real time and to discuss them soon after making them, data are likely to reflect the true motivations, cues and strategies actually used in making decisions, whereas these factors may become distorted when eliciting data retrospectively.

Such features foster the collection of comprehensive, detailed, and accurate data. The relative strengths of performance interviews and those of retrospective techniques such as critical incident interviews have not been empirically compared, and it is beyond the scope of this report to make such a comparison. One way of viewing the two methods is that critical incident interviews target experience, whereas performance interviews target experience in practice. According to this view, the interview methods are complementary to one another. In this report we augment general interviews with both critical incident interviews and a variant of performance interviews, which we call "quasi-performance" interviews. The procedures we used for each interview method are described in detail in the next section.[3]

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[3] Our original intention was to interview WDs immediately after they had finished a simulated mission on the C^3-STARS high-fidelity AWACS simulator at Brooks AFB, dissecting with them a videotape of their own recent performance. This method resembled a performance interview as closely as possible given the constraints imposed by studying such a dynamic task. Before doing so, we decided to make an exploratory trip to Tinker AFB in order to a) conduct general interviews with the WDs stationed there, and b) collect pilot data using the videotape review method just described. Since we did not have access to a simulator at Tinker, we used existing videotapes of a team conducting a mission on C^3-STARS and asked interviewees to answer questions "as if" they were one of the WDs on the videotape, otherwise proceeding with the interviews largely as planned. We felt that these initial interviews would yield useful information, but more importantly would serve to hone our interview structure and method, tailoring it to the structure of the WD task for use in the "real" data collection using C^3-STARS. Unfortunately, we were never able to access WDs as originally planned, and so were not able to conduct real performance interviews. The "quasi-performance" interview data used in the current study are in fact the pilot data collected on that initial trip to Tinker. Further, there are a number of drawbacks to using this data, the main ones being a) we did not interview as large a number of experienced WDs as we had hoped to, b) the "lane defense" configuration depicted on the videotape does not usually generate much team interaction, c) the interview structure, based loosely on PARI, was extremely provisional and was not a good fit to the structure of the WD task, and d) the technique was not a true performance interview (since interviewees were reviewing someone else's performance, they were not put in the position of actually making decisions, and so we would expect that data about the cognitive underpinnings of task performance would be less accurate). In this study we have called these interviews "quasi-performance" interviews, in that they exploit some, but not all, of the strengths of performance interviews but not all of them. Nevertheless, although the use of these data restricted the scope of our analysis, the description we were able to derive is no less valuable.

METHODOLOGY

There are a large number of knowledge elicitation techniques for describing and documenting the knowledge underlying task performance (see Cooke, 1994 for a review). As mentioned before, we used a mixture of general interviews, critical incident interviews, and a "quasi-performance" to target knowledge at different levels of detail and to converge on a coherent set of findings useful for the design of SynTEAM. Here we describe the methods used in detail.

Preparation

---General Interviews

General interviews were used to gather broad information about the WD task and to elicit context-free, stable domain knowledge. During the initial stages of this project we analyzed WD documentation and watched videotapes of teams of WDs performing missions on C^3-STARS, a high-fidelity AWACS simulator. We also had the opportunity to talk with knowledgeable SMEs on a number of issues and questions that arose during this time. Based on our understanding of the WD task as constructed from these activities, we compiled a general interview guide (Appendix A, Section A) consisting of both questions that we wanted answered in a fairly direct manner and questions about issues with which we were already familiar, but on which we wanted another perspective. Questions were designed to provide general background on what is involved in being a WD, task characteristics, task demands, typical operating characteristics, team interactions, and challenges facing WDs. A number of the questions in the general interview guide were taken from the "Knowledge Audit" inventory described by Pliske et al. (1997).

---Critical Incident Interviews

Critical incident interviews were used to sample the decisions that WDs make in stressful situations, and to examine the characteristics of these decisions. Our critical incident interview guide (Appendix A, Section B) was fashioned after that used by Klinger et al. (1993), but was aimed explicitly at eliciting and exploring incidents in response to which teamwork was a major factor.

---Quasi-Performance Interviews

The quasi-performance interviews were intended to provide detailed information about task performance and its underlying knowledge. Preparation for these interviews consisted of selecting and parsing a videotape to serve as a stimulus, and compiling an interview guide of questions to ask. First, we selected a videotape of a WD team performing a simulated mission on C^3-STARS, the high fidelity AWACS simulator located at Brooks AFB. The simulator has three WD consoles arranged in a row with an SD console located behind them (just like on the AWACS aircraft). The videotape depicted

the contents of the center WD's scope only. All WDs' voices were clearly audible on the video tape. Pilots' voices could also be heard, albeit faintly: hence, interviewees could hear everything that was going on, but could only see the scope of the center WD. The picture on the videotape mirrored the center WD's scope *exactly*: that is, if the center WD zoomed in or out on his scope then the videotape reflected this.

The mission captured on the tape was called Aaragon, a mission in which the WDs had to control fighters defending a fictional country against attacks by a fictional enemy, and also clear the way for friendly strike aircraft to penetrate enemy airspace. Responsibilities were divided among the WDs geographically ("lane defense"): the AOR was divided by straight lines into three horizontal lanes (North, Center, and South), with the center WD controlling the center lane. This particular tape was selected because Aaragon was identified by a SME familiar with the studies carried out on C^3-STARS as the most difficult of the simulator missions for which videotapes were available, and the team on the tape was identified by the SME as the best performing team. Further, while the lane defense configuration is not particularly conducive to team interactions (and is not commonly used now), nearly all team interactions on the tape involved the center WD, because his lane is adjacent to both the North and South lanes.

We reviewed the videotape with the aid of a SME, and identified two encapsulated "scenarios" for use as foci in the quasi-performance interviews. These scenarios fit our criteria of including both intense action and team interaction. The first scenario, the "air refueling" scenario, was an eleven-minute section of tape in which the center WD was coordinating and controlling a number of air refuelings involving his and others' aircraft while under time pressure. The "air battle" scenario was a twenty-minute tape section during which an air battle took place on the boundary between the Center and the North lanes. In order that discussions with interviewees be manageable, we asked a SME to divide each scenario into segments, one to three minutes in length, containing sets of events that were both cohesive enough to be interpretable by interviewees as a "whole", and significant enough to warrant discussion. These criteria were used to identify nine tape segments for the air refueling scenario and eleven segments for the air battle scenario.

Finally, we were aware that simulator missions typically build up in intensity over time, allowing WDs to "ease in" to the high workload encountered in the middle of such missions. Both of our scenarios were taken from the middle of the tape, well into the overall mission. Presenting the scenarios "cold" would have deprived interviewees of the context needed to reasonably interpret what is going on. However, playing the entire tape up to the start of each scenario would take too much time. To provide sufficient context in a reasonable amount of time, a SME identified "context building" segments to show the interviewees prior to showing each scenario. The first six minutes of the tape was identified as a "general introduction" to familiarize interviewees with the mission set-up and the taped WDs' voices. We then identified "scenario introduction" segments immediately prior to each scenario. These were intended to provide interviewees with enough immediate context to get them up to speed for the following scenario. The introductions lasted nine minutes for the air refueling scenario and just under three minutes for the air battle scenario. The time difference between the scenario introduction segments

was due to there being a higher density of events just prior to the air battle scenario than there was just prior to the air refueling scenario.

The quasi-performance interview guide (Appendix A, Section C) was built around a set of situation awareness probes designed to assess each interviewee's understanding of the situation at the beginning and end of each scenario, and a set of questions based on those used in PARI interviews (Hall et al., 1995) designed to elicit the knowledge and procedures underlying task performance. In PARI interviews, interviewees step through a realistic problem, at each step answering set questions aimed at eliciting **P**recursors (reasons for actions), **A**ctions (what the interviewee would do), **R**esults (of the actions), and **I**nterpretations (of the results), hence the "PARI" acronym. Treating the short videotape segments as "steps" analogous to PARI solution steps, we oriented our questions toward the WD task as we understood it, while maintaining the basic PARI categories as best as we could.

During the quasi-performance interviews, since interviewees were watching other WDs on a videotape rather than performing the task themselves, we could not have interviewees generate actions and then follow through on the results and interpretations of those actions, as in a PARI interview. To address this problem, we generated two separate sets of probes, the "next action" probes and the "last action" probes. Immediately before each tape segment was played, the interviewee was asked to imagine that he was the WD on the videotape (the center WD), and the "next action" probes were used to determine what the interviewee would do and the reasoning behind these actions (just as is done in PARI). Immediately following each tape segment, the "last action" probes were used to identify what actually happened during the segment, to interpret these events, and to elicit a critique of the performance of the WD on the videotape.

Procedures

---General and Critical Incident Interviews

Researchers interviewed WDs according to the interview guides. For the most part, the interview guides were not meant to be used verbatim, and researchers remained flexible and opportunistic throughout each interview. Although the general and critical incident interview formats were designed independently of one another, it proved more efficient to embed the critical incident interviews within the general interviews, since WDs would often start describing critical incidents in response to general interview questions. When this happened, we seized the opportunity to explore the critical incidents in depth as they occurred spontaneously, rather than trying to elicit critical incidents "cold" in separate interviews. General/critical incident interviews took from two to four hours to complete, usually filling the entire time for which each WD was available to us.

---Quasi-Performance Interviews

WDs were interviewed in groups of up to 3. After an initial introduction to the general aims of the study, a verbal description of the contents of the videotape, and a description of how the interview would proceed, interviewees were given mission briefing packets to study. These packets were identical to those provided to the WDs on the videotape prior to their performing the simulated mission. This study period generally took around 15 minutes, after which WDs were given the opportunity to ask the researchers questions. One of the interviewers then reiterated the interview procedure, stating that interviewees would be watching a videotape of the center WD's scope taken during a simulated mission employing the lane defense configuration, and that interviewees were to imagine themselves as the center WD. While the "general introduction" portion of the videotape was played on a large-screen TV, one of the interviewers provided commentary, orienting the interviewees to features on the screen and identifying WDs' voices. At the end of the general introduction, the same interviewer fast-forwarded the videotape such that the picture remained visible on the screen, albeit at high speed and without the accompanying audio track. This procedure allowed interviewees to follow the unfolding of the scenario, providing additional context, while also saving time compared to playing the videotape at normal speed. The interviewer again provided commentary on the events on the screen during this time. The interviewer stopped providing commentary when the tape reached the beginning of the introduction for the chosen scenario, returned the tape to normal speed, and left it to play up until the beginning of the actual scenario.

Each interviewee then paired up with one of the interviewers in front of a 20" television and VCR. Interviewees were given paper copies of the terrain map depicted on the videotape, and were asked to mark the positions, headings, and call-signs of both friendly and enemy aircraft, as they remembered them to be just before the tape was turned off. Interviewees were also questioned about the current state of the scenario, using the "situation awareness" probes (Appendix A, Section C). The purpose of this procedure was to assess each interviewee's "situation awareness": that is, whether or not the interviewee accurately understood what was going on. This was done so that interviewees' comments could later be interpreted in light of how well they understood the situation. Following the situation awareness probes, the interviewer started stepping through the videotape, asking appropriate questions at appropriate points: before each segment of tape was played the interviewer asked the "next action" probes (Appendix A, Section C), and after each segment of tape the interviewer asked the "last action" probes (Appendix A, Section C). Interviewers were encouraged to be flexible and opportunistic in their questioning. This procedure was repeated until the end of the scenario had been reached, after which interviewees' situation awareness was again assessed using the same method.

Participants

Twenty male AWACS Weapons Directors (WDs) served as interviewees. Nineteen of these were currently stationed at Tinker AFB, OK, while one was stationed at Brooks

AFB, TX. Most interviewees participated in either a general interview and a critical incident interview or in a quasi-performance interview using one of the two scenarios. However, where time allowed, some interviewees covered more than one scenario in their quasi-performance interview, while one interviewee participated in a general/critical incident interview and covered both scenarios in the quasi-performance interview. The experience and participation level of each WD is documented in Table I.

Table 1. Experience and Participation Level of Participating WDs

WD	Loc.	WD Exp.*	Special Exp.	General/ Crit. Inc.	Refueling Scenario	Battle Scenario
1	Tinker	2y 3m	Instructor		√	
2	Tinker	2y				√
3	Tinker	10m			√	
4	Tinker	10m			√	
5	Tinker	4y		√		
6	Tinker	1y 4m		√		
7	Tinker	10m		√		
8	Tinker	4y	SD	√		
9	Tinker	4y 6m	Instructor	√		
10	Tinker	2y			√	
11	Tinker	4y	SD			√
12	Tinker	4m			√	
13	Tinker	1y			√	
14	Tinker	7y	SD	√		
15	Tinker	1y		√		
16	Tinker	5m		√		
17	Tinker	3y			√	
18	Tinker	2y				√
19	Tinker	10m			√	√
20	Brooks	5y	Instructor	√	√	√

* First year of experience is spent in training.

To summarize the information in Table I, eight WDs had under one year of experience (i.e., they were still trainees), six had between one and three years of experience, and six had over three years of experience. Of this last group, three were SDs and three were instructors. Nine WDs participated in general/critical incident interviews and twelve participated in the quasi-performance interviews (with one WD participating in both formats). Within the quasi-performance interviews, nine covered the refueling scenario and five covered the battle scenario, with two WDs covering both scenarios. Table II shows the experience level of WDs broken out by interview participation.

Table II. Experience Level of WDs Organized by Interview Participation

Interview Format	n	Experience Level (y-m)	Mean Experience (y-m)
General/Critical Incident	9	0-5, 0-10, 1, 1-4, 4, 4, 4-6, 5-0, 7-0	3-0
Performance: Refueling	9	0-4, 0-10, 0-10, 0-10, 1-0, 2-0, 2-3, 3-0, 5-0	1-9
Performance: Battle	5	0-10, 2-0, 2-0, 4-0, 5-0	2-9

DATA ANALYSIS

All interviews, recorded on audio tape, were transcribed immediately upon returning from the data collection trip. Transcripts were augmented by notes the interviewers had made during the course of the interviews. After transcription was completed, it was clear that the PARI structure we had used for the quasi-performance interviews did not fit the structure of the WD task. The PARI structure was derived from a model of problem solving based on research on the troubleshooting methods of avionics technicians. While this structure does generalize to tasks other than avionics troubleshooting (e.g., Fahey et al., 1997), it did not capture the dynamism of the WD task, nor did it well represent multitasking. To better understand the data (and to formulate a model that could generate an interview structure for further data collections), we constructed a schema to describe the cyclical nature of the process by which WDs interact with their environment. We then independently reviewed our transcripts and identified "themes" for further analysis, using the new schema as a guide to interpreting the data (replacing the PARI schema, in the context of which the data was collected). Themes were predefined as issues facing WDs during the course of mission performance that cause them particular difficulties[4]. After a number of brainstorming sessions, in which these themes

[4] Themes were derived from data from all three interview formats. Although, on the whole, the general interviews provided background knowledge while the critical incident and quasi-performance interviews provided detailed, concrete examples of task performance, there was nonetheless some overlap between formats. For example, in the general interviews interviewees often illustrated the points they were trying to make with concrete examples of task performance, while in the quasi-performance interviews specific

were discussed and explored in more depth, we decided to use "decision requirements tables" to represent our data, since these are a good way of standardizing verbal protocol data. In turn, the tables that we each produced were consolidated and compiled, and a task description and specifications for SynTEAM design were produced.

In the next section of the report, we describe the formulation of our interpretative schema for the WD task, and then describe the process through which we derived the decision requirements tables.

Describing the Interaction Between WDs and their Environment

There were two reasons for constructing a schema to describe the WD task. The first was to motivate an interview structure that would better facilitate the collection of data in future interviews with WDs, in the same way that PARI facilitates collecting data from troubleshooters. The second was to provide a framework for organizing the data that we had already collected using the PARI framework.

---Underlying Model

The main problem with using PARI for collecting data from WDs was that the PARI structure was a poor fit to the WD task. The WD task is very dynamic and event-driven, whereas PARI is most useful for capturing performance on tasks driven by stable goals such as troubleshooting tasks. This suggested that another structure would be more appropriate for describing the WD task, so we set about developing a schema that would more accurately capture the thought processes underlying the WD task. The initial step in developing the new schema was to identify existing generic models of cognitive processing that *could* motivate the new structure, in the same way that a model of problem solving as serial hypothesis testing had motivated PARI. We reviewed a number of models that address real-time, dynamic tasks: Observe-Orient-Decide-Act (OODA) Loops (Whitaker & Kuperman, 1996), an enhanced version of Neisser's (1976) Perception-Action Cycle (Adams, Tenney, & Pew, 1995), and a model of human-computer interaction described by Norman (1984). All models were very similar in that they described a cyclical process of perception, thought, and action: for our purposes, the crucial step was how to carve the cycle into appropriate segments in order to provide a schema to describe the specific task at hand. We first identified the informational and cognitive categories important to task performance, then arranged these into a perception/action cycle that seemed to well describe both how WDs carry out the many tasks they are called upon to perform and how they integrate these tasks into the job as a whole. Finally, we verified that this schema was a good fit to the WD task as a whole by retrofitting it to the quasi-performance interview data we had already collected.

---An Initial Schema to Describe the WD Task

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actions were often related to general principles. All analyses presented in this report reflect data from all interview formats.

The initial structure, called PIGPEN, derives from general frameworks (listed in the previous section) as applied WD performance (as determined from the interview data):

P - **P**erceive events in the environment

I - **I**nterpret these events

G - Attach high-level **G**oals to these events

P - Integrate these events into a "big picture" and formulate a **P**lan (or **P**lans)

E - **E**valuate this plan (these plans)

N - Decide on a specific set of **N**ext Actions to execute the chosen plan

First, the WD perceives events in the environment. For example, the WD might notice a new track in hostile territory, a radio call that a pilot bailed out, a "Bingo" call from one of his fighters, and an undirected comment made by the WD controlling the North lane that there are more hostile tracks in his lane than his fighters can handle. He then interprets these events. For example, the new track may be inferred to be new hostile aircraft coming into the lane, the bail-out might be identified as a particular aircraft being shot down, the bingo call would be interpreted as an aircraft needing gas, and the comment made by the other WD might be interpreted as indicating that the other WD is overloaded and needs help. Next, the WD attaches goals to each of these events. For example, the new track would have to be intercepted, the downed pilots rescued, the low-fuel aircraft refueled, and the north WD helped if possible. After all the events of interest are noted and understood, the WD forms a game plan (or plans) for attaining the goals. This is where WDs allocate their resources to targets, and plan what to do next. The WD then evaluates the plan or plans and, once decided on a particular course of action, identifies individual actions in the order that they would be performed.

---Testing the Schema

We tested the schema by retrofitting it to the existing quasi-performance interview data, step by step. Although we allowed that the interview data might not have sufficient detail to allow us to test the utility of some aspects of the new schema, we nevertheless found several shortcomings. First, in practice it is difficult to distinguish between the "perceive" and "interpret" categories: for example, the WD might say "there's an unknown track over hostile territory: it is probably a bogey". It is not natural for WDs (or anyone else for that matter) to identify something without attaching meaning to it. Second, WDs do not seem to decide on goals for dealing with events, except at the most abstract levels, before they form an explicit plan. Although events are often unambiguously paired with goals at an abstract level (e.g., the ROE might dictate that an incoming hostile aircraft *has* to be intercepted) the method by which each goal is achieved cannot be decided out of the context of all else that is going on. For example, although a hostile aircraft needs to be intercepted, exactly how to do this will depend on how the WD's limited resources are otherwise committed: the closest set of fighters might not be able to make the intercept without endangering some other part of the mission. After assessing the situation (integrating the new events into all else that is going on), WDs typically

formulate and evaluate one or more plans. Strategies, prior experience ("have I seen something like this before?"), and the priority level of each goal are all factors in formulating a plan. For this reason, the "Goal" step should be absorbed into the "Plan" step, and "Priorities" should be assigned to each event after the planning stage in order to detail the exact actions to perform next. In reality, the planning stage is a major part of the WD's job. Because in a typical mission there are multiple constraints to satisfy at any one time and limited resources with which to do so, WDs often have to make tradeoffs in order to satisfy the maximum number of goals to the maximal extent. This involves some trial and error, as plans are formulated and evaluated. In this sense, the WD task is unlike many other "naturalistic decision making" situations in which the accuracy of the situation assessment is the prime determinant of whether a good decision is made (Klein, 1993).

---The Final Schema

Based on our limited data, we decided on a final schema (Figure 3). This schema was used to interpret the data we had already collected. Currently, this schema could be used to generate a new interview structure that would correspond more closely to the way WDs actually think than did the PARI structure, and should lead to the collection of better data. In the future, additional data from true performance interviews could be used to expand the schema into a more complete model of WD performance.

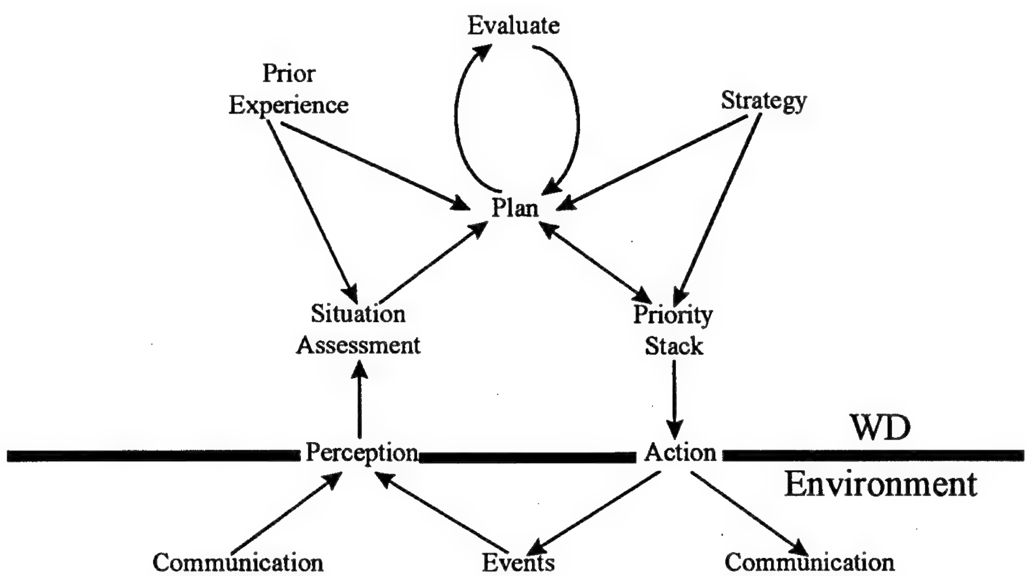

Figure 3: A Schema for the WD Task

From Verbal Protocols to Decision Requirements Tables

---Brainstorming Sessions

Each of us independently reviewed our interview transcripts and identified WD "themes", defined as issues facing WDs that cause particular difficulties or aspects of the

task that are particularly challenging, using the schema outlined above as a guide. These themes formed the foci of our discussions in subsequent meetings. In these meetings, it became clear that the themes could be organized according to two broad categories that seemed to capture what WDs spend most of their time doing: gathering information from the environment to maintain situation awareness and using their information and knowledge to make decisions that affect the environment. We also considered a third category, teamwork, to focus attention on our main concern here.

A further brainstorming session focused on what we wanted to learn from our data. Based on our data's limitations, we decided to list the tasks and actions performed by WDs, and also the cognitively-challenging events and scenarios faced by WDs. From these lists we made our decision requirements tables.

---Decision Requirements Tables

As a standard format for representing our inventories of tasks, actions, and events, we chose a format inspired by "decision requirements tables", used extensively by Klein and his colleagues as a way to represent verbal interview data in a useful format. Typically, decision requirements tables lay out information such as a description of a decision made, the cognitive requirements of that decision, and the cues and information used in making the decision. However, there is no standard format for these tables, and we customized as we saw fit. Since the WD task is so multifaceted, with decisions being made at a number of levels, we used three formats:

1) Subtasks Analysis Tables

Subtask	Decisions	Information/Cues	Component Actions

The subtasks analysis tables were initially used as a first pass at decomposing the WD task, to enumerate and analyze the major subtasks performed by WDs. SynTEAM should *at least* support performance of these subtasks. However, as we got further into the data analysis we realized that these tables were useful for representing subtasks right down to the switch action level.

2) Actions Analysis Tables

Action	Cognitive Workload

In these tables, we estimated, at a qualitative level, the workload generated by each action (task component) identified in the subtasks analysis tables.

3) Events Analysis Tables

Event/Action	Challenges	Decisions	Errors

These tables describe the environmental events typically encountered by WDs, and characterize the decisions made in response to these events. These tables thus capture decisions made at the strategic and tactical planning levels, as opposed to the subtask level decisions captured by the subtasks analysis tables. For example, the events analysis table would look at decisions such as how to respond to a hostile threat, while the subtasks analysis table would capture the decisions that need to be made once it has been decided that the appropriate response is to send a particular fighter, such as the best route to send it on.

All tables were pooled and duplicates eliminated. These tables were then used as data to derive the task description, presented in the next section.

WD TASK DESCRIPTION

The aim of building SynTEAM is to provide a research platform on which to study the effects of various interventions on the effectiveness of WD-like teams. The challenge for designing SynTEAM is deciding how the real world WD task can be distilled in a learnable synthetic task while preserving the ecological validity of the real task. Accomplishing this requires first identifying the task characteristics that define the WD task and drive WD team performance, then building SynTEAM to share these characteristics. To do this, we generated a task description from the information captured in the decision requirements tables, constantly referring back to the raw protocols for validation and enhancement. We also derived, from the description, a preliminary set of specifications for SynTEAM design: these will be presented following the task description.

Our task description is divided into two parts:

1. General characteristics or context-free attributes of the WD task: For example, WDs can freely talk to each other at any time during operations. This suggests SynTEAM WDs should be similarly enabled. It also suggests that modes of communication might be an interesting issue for study in a SynTEAM environment.
2. Specific events that occur during the course of a mission: These are most useful in scenario design and include not only the descriptions of the events, themselves, but also descriptions of how WDs deal with the events.

General Characteristics

Ten broad characteristics of the WD domain stand out as "defining" features:

- Dynamic, dense environment: WDs have to contend with a large quantity of rapidly changing information. Situations can quickly develop from routine to crisis, and WDs often work under tight time constraints. WDs must work to stay on top of the situation at all times, since falling even a little behind a routine situation can turn disastrous as the situation develops into something more critical.
- Perceptually-demanding: Because the WD environment is so dynamic, the WD task is extremely perceptually-demanding. Not only do WDs have to track resources that are moving around the airspace, but they must also calculate complicated "intercept geometry" to bring two or more moving tracks together at a predetermined point in space. Often, at least one track is not under the WD's control, and so a small error in the wrong direction could result in a missed intercept.
- Multitasking: WDs often have to perform more than one task at one time: for example, a WD controlling fighters might be monitoring a number of hostile intercepts all happening at once. Many tasks require continual attention, and so there is often considerable temporal overlap. WDs need to prioritize tasks, estimating when each needs to be revisited, and paying more attention to critical tasks or tasks that are nearing a critical point.
- Ill-defined problems: WDs are often faced with problems and situations to which there is no one correct response. For example, there may be more than one way to direct a fighter to deal with an incoming hostile threat, and WDs need to project forward to estimate which solution would have the most advantageous outcome.
- Division of labor: WDs cope with the amount of work involved in controlling a mission by dividing mission responsibilities among themselves. There are two common ways of dividing responsibility: 1) geographically, where the AOR is subdivided into "lanes", and each WD is responsible for everything that goes on in one lane, and 2) functionally, where the AOR is not subdivided, and each WD performs a different function in support of the missions in the AOR. Currently, the functional division of labor is by far the most common.
- Hierarchical team organization: The SD is a big part of the team, since a mission will involve many decisions that WDs are not authorized to make. How much authority WDs have will vary from mission to mission and from SD to SD, but WDs do not usually decide when to scramble new aircraft or make large strategic decisions such as which aircraft to commit to which hostile tracks. However, since WDs are in a privileged position to understand what is going on, a WD will typically approach the SD with both the problem and the solution, and the SD will often agree.
- Free flow of information: The most common way for WDs to communicate among themselves is verbally; either over Net 2 (the "WD Channel") or using "Net 4" (face to face communication). Both of these are "public" channels, in that all WDs can hear what is being said, and so most information being passed is *in principle* accessible to

all WDs. Further, since WDs can listen to all the radio frequencies, information passed between WDs and pilots is also effectively public.

- Overlapping mental models: Although WDs take on different responsibilities within a mission, all will have received the same training, and so there is no specialization of function. For example, a WD might control fighters in one mission, and tankers in the next. This means that WDs' mental models of the WD task (stable task understanding) overlap considerably. Each WD understands not only his own responsibilities but also the responsibilities of the other WDs on the team.
- Overlapping situation models: WDs tend to share a lot of information with each other, and, since they are usually working within a common airspace using public channels, it is not uncommon for all WDs to be highly aware of everything that is going on. However, during periods of intense activity WDs get so involved in their own responsibilities that they cannot keep up with everything else going on.
- Opportunistic cooperation: The most interesting team interactions arise opportunistically during times of crisis or high workload. Even though all WDs have their own responsibilities and duties, they have to be extremely flexible, working together and taking on new responsibilities in order to solve unexpected problems. WDs often actively enlist the help of other, less busy WDs, and they try to look out for one another, helping out when the need arises.

These broad characteristics have many ramifications for how WDs perform their duties. Next, we describe the general characteristics of the WD task in more detail, looking at task demands and WD strategies. We have divided the description into the following categories:

- Team composition and configuration
- Mission characteristics
- Task performance
- Information flow
- Teamwork
- Interface issues

---Team Composition and Configuration

- WD teams are usually comprised of at least 3 WDs and an SD. All WDs receive the same training, while SDs receive special SD training in addition to the training they get as a WD. WDs on a single team often differ in experience level, and team personnel is often changed. The SD is often not the most experienced person on a team: while experienced officers are often promoted to SD, enlisted personnel cannot be SDs, and so it is not uncommon for SDs to have under their command much more experienced enlisted personnel.

- Mission responsibilities are divided up among WDs depending on the demands of the particular mission. Teams are configured in anticipation of the events and workload that a particular mission will entail. The goal is not to overload any of the WDs. There are two common divisions of labor, geographical and functional, with the functional set-up being most common. A common division of labor is:

  - Check-in: when a friendly aircraft takes off, the check-in WD contacts it and determines if it is a scheduled flight according to the Air Tasking Order (ATO). If it is scheduled, the check-in WD determines whether it is configured as described in the ATO ("as frag'd"[5]). If it is not scheduled, its identity, description and mission are determined. As aircraft near the AOR, the check-in WD hands control over to the AOR WD, "pushing" aircraft onto the AOR WD's primary radio frequency, and informing the AOR WD of any deviations from the ATO. It is also the check-in WD's responsibility to inform the AOR WD and the SD when a scheduled aircraft fails to appear. The check-in WD also checks aircraft back out as they leave the AOR.

  - AOR (also known as DCA [defensive counter-air]): the AOR WD controls aircraft within the AOR, coordinating fighters to man the Combat Air Patrol (CAP) points, and overseeing any other activities that may be going on in the AOR (such as escorting a diplomatic flight, or controlling a rescue operation). The AOR WD is responsible for monitoring and intercepting any threats that materialize in the AOR.

  - Tanker/HVA (High Value Assets): as aircraft run out of fuel, the AOR WD sends them to the airborne tankers, passing control over to the Tanker/HVA WD. Refuelings are usually scheduled during routine missions, but during combat situations refuelings occur on an as-needed basis. The Tanker/HVA WD is then responsible for on-the-fly scheduling, expediting the refueling of critical aircraft, and returning to base (RTB) aircraft that cannot be accommodated. After each aircraft is refueled, it is sent back to the AOR, and control is returned to the AOR WD. The Tanker/HVA WD is also responsible for controlling the high value assets involved in a mission, such as reconnaissance aircraft and the AWACS aircraft itself. In large missions, responsibility for tankers and HVAs might be divided between two WDs.

  Other common responsibilities are "Strike", who controls and monitors strike packages going in to enemy territory, and "Assist", who aids a designated WD (e.g., Check-in Assist, Strike Assist) when workload is anticipated to be high.

  The WD console supports flexible division of responsibility by allowing all WDs access to all system information, all the while allowing WDs to customize the settings on their individual consoles in order to focus on the most relevant information. An SD oversees and directs the WDs, and is the link between the WDs and the MC and between WDs and Ground Control. The SD is involved in deciding when to scramble

[5] The ATO is made up of smaller "fragmentary orders" for single units such as a flight of aircraft. Hence the term "as frag'd" to signify agreement with the fragmentary order on the ATO.

new aircraft, and is the WDs' "authority" for making strategic decisions such as which aircraft to commit to a hostile track or whether or not to shoot at a hostile track.

---Mission Characteristics

- Missions usually involve a number of separate activities, all of which WDs must monitor and control. The most common activities are patrol, defense, strike, escort, and search and rescue. A single mission usually involves a mixture of these activities, often with a number of activities going on at once.
- Because responsibilities are divided among WDs, different WDs become busy at different times: the "cadence" of the mission is such that some WDs will be extremely busy at the same time that other WDs have little to do. For example, the check-in WD is busiest at the beginning of the mission, while the AOR WD is busiest in the middle of the mission. It is during such times of differential workload that the most team interaction tends to take place, as WDs work together to spread the workload to avoid any one WD becoming overloaded.
- Routine missions are tightly scheduled. WDs know exactly who will be flying, and when and where they will be flying. All this information is contained in the Air Tasking Order (ATO). WDs have to be vigilant, noting deviations from the ATO and passing this information on to the other WDs and the SD. However, when unexpected events occur, such as an enemy attack, WDs need to improvise and the ATO becomes less important.
- WDs always have to follow precise Rules of Engagement (ROE). Rules are specified for different levels of activity, from peacetime to war, with a number of gradations in between. The ROE tell the WD what can be done at each level, such as how to address and intercept hostile or unknown aircraft. Before deciding upon an action, WDs need to consider the current ROE and make sure that any decision is appropriate given the current rules.
- Each mission is preceded by a briefing. During the briefing, WDs and the SD discuss the mission plan and schedule, review the ROE, and work out in advance how events will be dealt with. Each WD's roles and responsibilities will be clearly worked out. WDs make verbal "contracts" with each other regarding what and how information will be passed. WDs try to anticipate all that could happen in a mission, and make contracts establishing how they will help each other out in difficult situations. Contracts are a very important part of the total mission, and WDs take them very seriously.
- The WDs' environment is very dynamic, often with many things going on at once. Even in a routine mission, WDs have to prioritize tasks efficiently in order to service each in a timely manner: attention must be rotated between tasks, and each task must be revisited at critical points. A WD cannot afford to be lax even in times of low workload, because a dangerous situation can unfold very quickly, and if a WD is behind or unprepared important tasks can easily be forgotten in the context of new

events. In situations where WDs are very overloaded, it is not uncommon for them to completely lose situation awareness all at once.

- WDs often have to solve ill-defined problems. Ill-defined problems are those for which there is no obvious single solution that is the "best" solution. A common problem of this kind is caused by unknown or enemy aircraft whose intent is not clear. For example, in tense situations enemy aircraft will often fly close to international borders, not quite crossing them but remaining in threatening positions. WDs have to monitor such aircraft constantly to try to determine what that aircraft is going to do (will it become a threat?). Another problem is caused when missions and ROE change after take off: if changes are not communicated clearly WDs can often be uncertain about what to do in encounters with enemy aircraft. When in doubt, WDs ask the SD for clarification. Further, information is often inaccurate or badly transmitted: Because of the high workload, pilots and other WDs can make mistakes in their transmissions of information, and the noisiness of the communication channels often leads to misinterpretation of information.
- Sometimes WDs don't get the resources they expect. This means that they often have to form new strategies spontaneously. Although missions are organized so that WDs will have access to enough resources to do their job (preferably meeting threats at least one-on-one), when unexpected events occur WDs can often find themselves short or resources.

---Task Performance

- In principle, all WDs have access to all information. However, there is often too much information for one person to handle (after all, that is why WDs operate as a team), and so WDs generally only attend to information that is relevant for their own needs. WDs maintain situation awareness and make decisions by integrating relevant information from the scope, the radio (information from pilots, other WDs, the SD, and intelligence sources), and the ATO.
- WDs often change the expansion on their scope, periodically zooming out to do a "clock sweep": using the smallest screen magnification (the "big picture") to take stock of events in the whole AOR and to look for any changes or new tracks.
- WDs usually use a set of relative coordinates for transmitting aircraft positions, using a base altitude and a "bullseye" point on the screen relative to which aircraft positions are calculated. Base altitude and bullseye points are preset, and change from mission to mission. This coordinate system is intended to prevent the enemy from interpreting commands issued by WDs. Remembering to offset all coordinates is an added burden to WDs, and WDs must also remember not to report the positions of enemy aircraft using relative coordinates: knowing their own absolute positions, the enemy could easily work out where the base altitude and bullseye positions are.
- WDs must maintain efficient "fighter flow". This involves trading off between having too many assets airborne and risking overloading themselves, and having enough assets available to complete the mission. WDs solve this problem by planning ahead as

much as possible: refueling, scrambling and committing aircraft to deal with upcoming events as efficiently as possible.

- WDs must prioritize tasks, making sure the most critical ones receive the most attention and that each is revisited at appropriate intervals, yet not neglecting other tasks. WDs often use a strategy called "walking the clock" to make sure that nothing is neglected: after each task has been attended to, the WD zooms out and scans the screen in a clockwise direction, looking for the next task under his control, and so on until the whole screen has been scanned and all tasks serviced, at which point the cycle is repeated. WDs have to constantly reassess their priorities as the scenario changes.

---Information Flow

- Since WDs do not specialize in a particular role, each knows what information he needs to pass on, and to whom. Information is usually passed over Net 2, or sometimes "Net 4", so the intended recipient and the SD can always hear the message. WDs establish exactly how they will communicate with each other by making verbal contracts with each other beforehand. However, in times of high activity Net 2 and Net 4 are often saturated, so WDs often use console messaging, a kind of email between consoles, so as not to add to the verbal traffic. To avoid confusion and additional clutter, WDs also often silently rehearse verbal messages before speaking.
- Because there is so much information being passed, WDs cannot always be sure that any given message has been received: even if the recipient hears the message or sees it flash up on his screen, he might not absorb the information if he is very busy. WDs usually make contracts with each other to acknowledge any messages that are passed to them. If a WD doesn't acknowledge receipt of a message, the sender will either repeat it or somehow gain the intended recipient's attention, such as nudging him on the arm.
- WDs constantly communicate with the pilots they are controlling, constantly issuing "picture calls" to update their pilots with new mission-relevant information, such as enemy movements or other events happening in their vicinity, mission changes, and advance notice on any upcoming tasks. Information is usually only passed to pilots when something new happens. However, sometimes WDs issue picture calls even when there is no new information, since pilots are human and need to maintain situation awareness. This highlights a fundamental difference between the WD task and other control tasks such as UAV control, in which commands only need be issued when a change needs to be effected.

---Teamwork

- Missions in which responsibilities are divided by geographical area might proceed with little interaction among WDs, as long as each WD takes care of his own area and there is little spill-over between lanes. However, when aircraft do cross between one lane and another it is imperative for WDs to negotiate how to handle that aircraft, a negotiation that often involves control being handed from one WD to another.

- Missions in which responsibilities are divided according to function demand much more team interaction. For example, the AOR WD has to temporarily hand control of fighters going for refueling to the tanker WD. The WD controlling the tankers might already be trying to coordinate the fueling of other aircraft, perhaps "belonging" to a 3rd WD, and so the three would need to negotiate an acceptable fueling schedule according to the needs of each WD and the aircraft involved. WDs always need to keep other WDs informed of things that may affect them: for example, if a dogfight gets dangerously close to the location of the tankers, the AOR WD needs to tell the Tanker/HVA WD, so that he can move them.
- WDs try to remain aware of the "big picture", to the extent it is possible given the demands of the job, by monitoring what the other WDs are doing. They do this by looking at the whole area on the scope, and also by listening to others WDs' radio frequencies. While it is difficult for each WD to remain aware of the big picture in times of high workload, workload is often distributed unevenly and a WD who is relatively free will volunteer, or will be asked by the SD, to help another WD who is overloaded. For example, the AOR WD might ask the check-in WD to monitor the "big picture", looking out for new events, while the AOR WD is "zoomed in" on a tricky intercept.
- Noticing a WD "tunneled in", focusing on a small part of the airspace using a large screen magnification factor to the detriment of all else that is going on, is a sure sign that a WD is overloaded and headed for trouble. Because WDs share a common mental model of the task, each knows the common problems and errors associated with each role, and will try to help out.
- It is sometimes more efficient for a WD to ask another WD for information rather than to break concentration and look for the information himself, especially when asking for information regarding assets under another WD's control. It is also common for a WD to ask another WD for information that that WD has forgotten to pass on.
- In crisis situations, such as when a WD completely loses situation awareness, WDs sometimes "seize" other WDs' assets. At other times WD teams virtually reconfigure themselves, each WD taking on new responsibilities in light of the crisis situation. WDs are able to do this since all receive the same training, and the WD workstation supports flexibility by allowing all WDs to control all assets: to control an asset, a WD usually has to bring it up on his primary radio frequency. However, each asset is under one, and only one, WD's responsibility at any given time.

---Interface Issues

- The two dimensional scope displays three dimensional information: WDs have to be constantly aware of aircraft altitudes, the third dimension of airspace that is not represented graphically on the scope. WDs can find out aircraft altitudes from the TDs or by using an option that displays the track altitudes as part of their symbology.
- WDs need to work at a number of different levels of screen magnifications: WDs can use their scopes to zoom in on a portion of the airspace in order to closely control and

monitor aircraft, or zoom out to look at the "big picture". However, there are costs associated with both of these views: while zoomed in on a small area the WD cannot see what is going on in other areas of the airspace, and while zoomed out WDs cannot make precise bearing and range measurements or select specific tracks very easily, due to screen resolution limitations. These limitations are important determinants of WD behavior: the latter limitation requires that WDs spend a lot of their time zoomed in, enlisting other WDs and using the radio to maintain awareness of the big picture.

- Aircraft often fly so close together that they appear on the scope as a single track. At other times, even though there are in fact two tracks they may be so close together that they look like one. This can sometimes cause WDs to underestimate the strength of the enemy. On the other hand, friendly aircraft usually fly in flights of two or four, with the WD only talking to the lead pilot. The advantage of this is that the WD can treat a number of aircraft as a single unit, while the disadvantage is that he must often remember how many aircraft are represented by a single track (or what looks to be a single track).
- WDs "know their switches": although the WD console is superficially complex, WDs can perform most of the common operations with little effort wasted on figuring out which button to press.
- Only a small number of basic actions are required for WDs to perform their job efficiently. The apparent difficulty of the WD job derives from the complexity of the situations that WDs face, the amount of information they have to process, and the fact that WDs may have to perform many activities at once.
- Although WDs are trained to exercise precise control over aircraft, in reality fighters have their own radar that, over short ranges, is more precise than the AWACS radar. In real missions, the role of the WD is to guide fighters to within range of their target, be it a hostile aircraft or a tanker, after which the WD monitors the situation and keeps the pilot informed of events he might miss. For example, in a dogfight the WD would warn the pilots of any "spitters" (enemy aircraft that disengage and split off from the main battle).
- The AWACS radar has a 12 second sweep, meaning that the scope information is updated every 12 seconds and so can become up to 12 seconds out of date during the time a WD has to make a decision. WDs have to be aware of this, and extrapolate the positions of aircraft. This adds to the WDs' workloads and causes errors, but does not affect strategies for dealing with external events. Fighter radars update more quickly than the AWACS radar, and so when a fighter has a target on its radar the WD will rely on the fighter pilot's radio transmissions for up-to-date reports of when a target has changed heading.
- WDs can spend a disproportionate amount of time "tracking" objects whose symbologies have become detached. However, in a soon-to-be implemented updated AWACS system, this problem (i.e. sub-task) has been virtually eliminated.
- The WD's job is affected by the weather: WDs have to exercise different levels of control over their assets depending on the weather. Regulations state that air refueling

can only be done under conditions in which aircraft can see each other, and so WDs often need to work with aircraft to find it clean air.

Specific Events

In this section we describe how WDs deal with particular events and situations. Individual events always occur in a particular mission context, and a WD's response to any event depends on all else that is happening at that particular time. However, through sampling scenarios and critical incidents in our interviews, it is possible to build up a context-free picture of how particular events are dealt with, and an understanding of the contextual factors that determine exactly how an event will be responded to. Findings from this kind of analysis can be used both for scenario development (deciding which events to use in order to study particular task characteristics), and for suggesting performance metrics based on task processes, not just mission outcomes. We will outline some common events and situations faced by WDs, and explain how they deal with them.

In describing events, for the most part we assume a team composed of a Check-in WD, an AOR WD, and a Tanker/HVA WD.

---Routine Events

Each mission is precisely scheduled. During briefing, WDs are given copies of the Air Tasking Order (ATO), which details the flight schedules of all aircraft that will be flying on that team's "watch". Aircraft are scheduled to take off at a particular time, to fly a designated route, and to land at a particular time. Air refueling is also pre-scheduled. Missions are generally configured not to over-tax the WD team, and if a mission goes according to plan most events are manageable, with each team member having routine responsibilities for keeping the other WDs abreast of events as follows:

- The Check-in WD needs to identify and attach symbology to any aircraft taking off, checking whether they are as frag'd (as described in the ATO). Once this is done, he "pushes" the aircraft to the AOR or Tanker/HVA frequency (depending on what the aircraft is), and tells the appropriate WD that this has happened and whether or not the aircraft is as frag'd. The Check-in WD also takes control of aircraft that are going back to base.
- The AOR WD needs to tell the SD when anything out of the ordinary happens in the AOR, such as deviations from the mission plan. He tells the Tanker/HVA WD when an aircraft is coming to a tanker for refueling, and tells the Check-in WD when an aircraft is leaving the AOR.
- The Tanker/HVA WD monitors the refuelings and the positions of high value assets (HVA) such as reconnaissance aircraft. He informs the AOR WD when an aircraft leaves the tanker and re-enters the AOR, or when something happens with the HVAs that is not on the ATO. He also tells the Check-in WD when any tankers or HVAs are going back to base.

- The SD monitors the other WDs, and keeps them informed of any planned mission changes or changes to the ATO that he receives from the MC or Ground Control.

Each WD is responsible for informing, as appropriate, the other WDs, and the SD when anything happens that is not exactly according to plan (or if a planned event doesn't happen). The SD needs to be kept informed of almost all unplanned events. For example, the Check-in WD would have to tell both the Tanker/HVA WD and the SD if a scheduled tanker failed to appear. The Tanker/HVA WD would need to tell the AOR WD that the fuel will not be available as frag'd, and it would be the SD's responsibility to find out why the tanker did not materialize and to arrange for a replacement. This rule holds for both changes in events and changes in the timing of events: for example, the AOR WD would need to tell the Check-in WD if an aircraft was not going to check out at the scheduled time.

Unsurprisingly, the most interesting team interactions occur when crisis or difficult situations develop, going beyond missions in which the only unexpected events are deviations from the ATO. When WDs encounter unknown or hostile aircraft, the main priority is to defend the airspace and friendly aircraft. WDs become much more opportunistic: they need to use the assets they have efficiently, refueling and RTB'ing either when absolutely necessary or when it is most convenient, and scrambling new aircraft when needed. Coordination becomes paramount, since each WD has his own needs. For example, the AOR WD needs to make sure that there are enough fighters on station, and the Tanker/HVA WD needs to spontaneously form a refueling schedule. Both WDs need to work together to make sure that things happen, all the while keeping the SD and the Check-in WD informed of what is going on in order to minimize the chances of any "surprises".

---Non-Routine Events

Here we describe some of the non-routine events that were discussed during our interviews. While this is not a comprehensive list of all events that can possibly happen in all possible contexts, it gives a sampling of the cognitive demands placed on WD teams and the decisions that WDs need to make.

- Hostile threat

The AOR WD is responsible for addressing any threats that appear. When a hostile or potentially hostile track appears in the AOR, the AOR WD first needs to inform the SD. The SD and the WD often work together to decide what to do about it, with the SD coordinating with the Mission Controller (MC). A good WD will approach the SD with a solution as well as a problem, and SDs will often act upon WDs' recommendations. Once it has been determined that a track is a threat, the WD and the SD figure out how many aircraft are needed to address the threat, then figure out where these will come from. The first place to look is to aircraft currently in the air, taking into account what else they may be doing, their capabilities, and their fuel and armament status. Sometimes it is necessary to scramble new aircraft, typically done through the SD: the SD will coordinate with the MC and Ground Control to get the new aircraft, then tell the Check-in WD to expect the

new aircraft. As the situation unfolds, the AOR WD directs the friendly aircraft appropriately. How he directs will depend on the types of aircraft involved (e.g., "are the hostile aircraft faster than the friendly aircraft?"), and the current ROE (e.g., whether to shoot or head the hostiles off). Sometimes, if the hostile aircraft has not actually committed a hostile act (such as shooting, bombing, or "painting" an aircraft with its weapons radar), the friendly aircraft may have to shadow the hostiles, following them closely until they cease to be a threat or further action needs to be taken. This requires close monitoring, and working through the SD to decide when further action needs to be taken.

- Hostile track menacing the border

In sensitive situations, hostile aircraft often fly close to borders, not quite crossing them, to "test" the friendly defense. It is the AOR WD's responsibility to make sure that a menace does not become a threat. As with a hostile threat, the AOR WD needs to tell the SD what is going on, and assign friendly fighters to monitor the menace. This situation requires constant monitoring, and the WD and the SD need to decide when the hostile ceases to menace and becomes a threat.

- Unknown track

The surveillance team is primarily responsible for identifying and attaching symbology to tracks that are not part of the mission, usually those originating outside of friendly territory. However, sometimes unknown tracks are not immediately identified. The AOR WD must first tell the SD that there is an unknown track, then monitor the track's progress until it gets into a threatening position. It is then treated as a threat. The ROE usually specify that the track has to be identified, and there are usually specific criteria for what counts as a valid identification (e.g., Visual ID, Beyond-Visual-Range ID). The AOR WD will usually send fighters out to ID it and, depending on the response, will either treat it as a threat or leave it alone.

- Defector

There are pre-specified actions that defectors must take in order to be taken seriously. Defectors must broadcast an identification code, and must fly slowly with landing gear down, weapons checked "safe", and fire control radar turned off. They must broadcast their intent on the Guard (common international) channel. Due to the potential for trickery, the AOR WD usually sends some of his fighters to investigate the defector and escort it to a base. This means essentially taking some friendly fighters out of the mission, and so the AOR WD and the SD have to decide whether to try to scramble new aircraft as replacements.

- Hostile track splits up

Aircraft seldom fly alone, and sometimes aircraft fly so close together that on the AWACS radar two aircraft can look like one track. Aircraft will often fly close to one another in order to fool the AWACS radar, then split up at the last minute, confronting the AOR WD with twice as many tracks as he previously thought. In such cases there is

pressure on the AOR WD to respond quickly in order to prevent any threats penetrating the friendly airspace. The AOR WD may respond in kind, splitting up his own flights into separate tracks (which requires permission from the SD), or may either direct some additional aircraft in from another area, scramble some new aircraft, or prematurely take some aircraft off the tanker if there is a real problem.

- Shooting down a hostile aircraft

Depending on the ROE, fighters often need to ask for permission to shoot. When a pilot asks a WD for an "open right to kill" (ORK), the request is relayed via the SD to the Ground Control, then relayed back to the pilot. After permission has been granted, the WD needs to monitor the situation closely, listening for the friendly pilot to announce that he has shot down the hostile track or for signs that the hostile track has shot down the friendly track. Regardless of the outcome, the WD needs to tell the SD, who then informs the MC and Ground Control of what happened. If the hostile was shot down, the WD needs to provide guidance to the pilot on what to do next, while if the friendly aircraft has been shot down, a Search and Rescue (SAR) mission needs to be initiated.

- Dogfight

When aircraft get close together in a dogfight, there is not much that the WD can do to help, since at that point the fighter radars are usually more capable than the AWACS radar. The role of the WD is to monitor the fight, waiting for kill calls, bail-out calls, and watching for "spitters" (hostile aircraft that "sneak out" of the dogfight unobserved).

- Strike Package

The AOR WD needs to make sure that there is a clear path for the strike package (bombers and their escorts) to go in. He will use his fighters to neutralize any threats that are in the way. Since strike packages are usually scheduled, the mission will be set up so that WDs have enough resources to do this while still being able to cover the rest of the airspace.

---How Events Generate Teamwork

As mentioned before, some team interactions are routine, based on how information needs to be passed on. There are few events which, in themselves, generate teamwork, except for crisis situations, where all WDs tend to work together to solve the problem. However, the most interesting team interactions arise opportunistically. Many interactions arise when a WD is over-tasked, when another may jump in and lend a hand. We observed some real examples of how this can happen in the critical incident interviews, and the main critical incidents are given in Appendix B. Here are some of the more common situations that give rise to team interactions:

- Too many aircraft checking in at once

During the early part of the mission, the Check-in WD can often become overwhelmed. Yet it is imperative that he keep up with the work. Since the mission proper won't have really started, the AOR WD usually helps out with check-in duties. If aircraft

are taking off from more than one airfield, the Check-in WD will deal with aircraft taking off from one airfield while the AOR WD will take care of the other.

- Too many aircraft in the AOR at once

Later on in the mission the reverse is true: the Check-in WD has little to do, while the AOR WD can be overwhelmed. Accordingly, the Check-in WD often helps out the AOR WD, performing tasks such as tracking aircraft and monitoring the "big picture" while the AOR is otherwise busy.

- Incidents in different parts of the scope

Sometimes the AOR WD has to deal with incidents in different parts of the scope. This can be difficult because it is often necessary to "zoom in" on each incident in order to see what is going on in sufficient detail, and so it is often not possible to monitor numerous incidents at the same time. The AOR WD will often enlist another WD to help out.

- Tracking a helicopter

Helicopters are extremely difficult to track, because they fly at a low altitude and at a slow speed. Because of this, they often disappear from the radar, and it is easy for a busy WD to forget that they are there. To make matters worse, helicopters are often owned by other agencies, such as the Army or the United Nations, and so often do not check in with the WDs. This can cause them to appear suddenly in the middle of the screen, as a "pop-up" track (see below). A WD will often recruit a less-busy WD to track a helicopter, since it requires too much concentration for someone who is busy elsewhere.

- Pop-up track

Sometimes an unidentified track will suddenly appear on the radar, or friendly aircraft will suddenly "lock on" to a target that is not on the AWACS radar. There is often a time constraint in these situations, since the "pop-up" can appear anywhere, including in friendly airspace. If the pop-up is a hostile aircraft it needs to be dealt with right away; however, it is important not to rush into action since the consequences of a friendly fire incident are very grave. The AOR WD, or whoever first notices the pop-up, needs to first inform all the other WDs and the SD. The AOR WD and the SD need to coordinate friendly fighters in the area, and the first priority is to identify the unknown track. This is usually done by friendly fighters working closely with the AOR WD, while the other WDs will work to determine if there are any friendly assets that they could have missed (such as helicopters that might have flown below the radar), or aircraft returning to the AOR without checking back in.

- Friendly aircraft shot down

When a friendly aircraft goes down, the WD needs to initiate a Search and Rescue (SAR) mission to recover any survivors, and coordinate any support aircraft that are needed. The AOR WD usually knows the location of the downed aircraft, but he has to pinpoint it exactly in order to run an efficient SAR mission. If possible, he will have some

nearby aircraft fly over the crash site. The SD often helps to launch the SAR package, and control of this will often be given to the least busy WD.

- Spill-over between lanes

When there is spill-over of hostile tracks or a battle from one lane to another, the WDs involved need to negotiate how to deal with it between themselves: this could involve passing control of friendly fighters from one WD to another, or one WD temporarily working within the other's lane.

- Shortage of resources

When a WD runs short of resources, he usually works through the SD to get more aircraft airborne, or with the Tanker/HVA controller to refuel the aircraft he does have. In some cases, such as when using the "lane defense" configuration, a WD can negotiate with another WD to "borrow" aircraft. For example, if an aircraft runs out of fuel when shadowing a hostile track, the WD might negotiate to get the nearest set of fighters to cover, regardless of who is controlling them.

- Refueling in bad weather

When refueling in bad weather, the tankers need to find "clean air" in which to work. This can require considerable coordination with the Tanker/HVA WD, who will often need to enlist the help of another WD to oversee other tasks while he works with the tankers.

- WD loses situation awareness

When one WD gets overloaded and loses situation awareness, it is up to the whole team to cover him and help him get back on track. The SD usually steps in, dividing control of the lost WD's resources between the other WDs, and working to help him rebuild situation awareness. A common way to do this is to zoom out the scope in order to see the big picture, and to listen to the radio for while to gradually figure out what is going on, before resuming control.

SYNTEAM DESIGN

A major challenge in designing an STTE is deciding exactly how to simplify the real world task without significantly altering its main characteristics. It would be very easy to oversimplify the task inadvertently. For example, real world air refueling takes quite a lot of time. If air refueling in the STTE is made extremely quick and simple, then decisions on whether or not to refuel an aircraft might be taken much more lightly. In addition, many real world task characteristics simply add cognitive overhead to the task. For example, the AWACS radar scope updates every 12 seconds, which causes screen information to become outdated even while audio information from pilots is continually updated. This does not change the fundamental characteristics of the decision to be made, but nevertheless adds to the overall workload and can cause errors and confusion, especially if the (outdated) screen information conflicts with the (current) audio

information. Whether to include such characteristics into SynTEAM is a judgment call, which depends on the kinds of studies SynTEAM is intended to enable.

Summary of CTA Findings

To recap, here are the most prominent findings from the CTA.

Task Characteristics

- Dynamic, dense, audio-visual environment, requiring multitasking and making heavy perceptual demands
- Varied duties and responsibilities and a variety of mission objectives
- Scheduled, rule-bound routine missions, but unexpected events and emergencies causing deviations from the schedule and changes to the rules
- Limited resources
- Small number of basic operations

Team Characteristics

- Hierarchical team structure, with SD or higher making most of the strategic decisions
- WDs flexibly divide responsibilities, producing differential workloads throughout the mission
- Overlapping mental and situation models

Team Strategies and Operating Principles

- Provide universal access to information
- Integrate information from scope and radios
- Remain aware of the big picture: Use different scope magnifications and "clock sweeps"
- Prioritize tasks effectively
- Pass on relevant information to other WDs and pilots, making sure it gets there
- Monitor each other
- Help each other out when the need and opportunity arises (opportunistic cooperation)

Major Errors and Problems

- Information overload, leading to loss of situation awareness
- Failures to coordinate or pass on information
- Errors in passing information
- Failure to interpret or absorb information correctly

Data Capture and Performance Metrics

SynTEAM should have some basic features for post-hoc analysis of team behavior:

- Mission reconstruction: SynTEAM should be able to replay a mission, recreating how aircraft moved around the screen, and signifying in some way when WDs performed actions (such as presenting WD actions in a text box). Replay should be synchronized across WD stations. If the replay facility is not practical to program, SynTEAM should *at least* have a capability similar to C^3-STARS, with the screen being sampled and dumped to a file periodically, and a "log file" being kept, recording all WD actions and scenario events. Another option is to use a multiplexer to capture the screens of each WD station and record them onto a videotape. If this is done, the video should be time-stamped to allow correlation with the log file.
- Voice data: SynTEAM WDs should wear microphones to capture voice data. Depending on how communication with aircraft is implemented, each WD's voice could be captured on a different audio track. There should be some way to synchronize the voice data with the scenario events and WD actions data, however they are captured (see point above).
- Experimenter station: a useful feature would be an option for an experimenter console, from which a researcher could monitor the mission progress, displaying each WD's scope in a window on a large screen and allowing the experimenter to annotate and make notes.

Many performance metrics have been refined using the C^3-STARS simulator, and most of these should be transferable to SynTEAM. However, many of these are "outcome" measures, such as kill ratio and total number of refuelings. SynTEAM should also capture some process measures. Process measures will indicate whether WDs and WD teams are exhibiting the hallmarks of good and poor teams. These measures can be related to outcome measures to determine which processes are most important for good team performance. Here are some ideas for process measures that warrant further development:

- Situation awareness probes: many existing synthetic tasks measure situation awareness by stopping the action, blocking out the screen and asking questions. Since this is such a popular method, SynTEAM should also have this capability. An interesting variant on this would be to be able to block out part of the screen: research on air traffic controllers has shown that they do not group aircraft by location, but by common purpose (Schlager, Means, and Roth, 1990); partially blocking out the screen would allow flexibility in researching this issue.
- "On-line CTA": when performing a CTA, we frequently use the questions "why?" to probe interviewees for the reasons and decisions underlying their actions. It is perhaps the most important CTA probe, yielding not only the motivations for interviewees' actions, but also their interpretations of the situation and the results of previous actions. In SynTEAM, it might be possible to capture at least some of this information as the task unfolds. The system could ask a WD to "say reason" after performing an

action, requiring him to explain why he performed an action. Collecting CTA data in such a way would present a huge advantage over collecting data retrospectively, as is usually done with dynamic tasks, and such a requirement would even be ecologically valid, since pilots, SDs, and MCs often question WDs in such a way. It should be possible to toggle this feature on and off.

- Secondary tasks: scenarios should include some low priority tasks that are not critical, yet which require attention and action, and on which WDs' performance can be easily measured. A number of these low-priority tasks could form a library of secondary tasks, and performance on these tasks should be correlated with workload: the less busy a WD is, the more attention he can pay to the secondary task. An example of a secondary task would be controlling aircraft on non-dangerous, non-strategic missions in a corner of the AOR not affected by the rest of the scenario. One idea would be to control a supply aircraft making periodic drops over designated spots: the WD would have to direct the aircraft to the spot, and issue a "drop" command when it is reached. The dependent measures could be accuracy of drops and drops missed. Another idea is to have WDs control a training mission, keeping the pilots away from the combat zone.
- Communication measures: WDs report that a better team will interact less: this is because WDs share mental and situation models, and teams with good models know what is going on and how information needs to be passed, reducing the need for WDs to query each other. Other WDs report that they use the electronic messaging system when the voice channels are saturated. Measures based on the amount of communication of each type could be useful as indicators of mental model overlap, although further details will have to be worked out when the basic SynTEAM design has been finalized.
- Keeping the "big picture": WDs stress the importance of staying aware of all that is going on in the AOR. However, they often get sidetracked, becoming preoccupied with a single task while ignoring others. SynTEAM should keep track of how often WDs zoom out their scopes to look at the big picture, and how often they stay zoomed in on a single area.
- Keeping aircraft informed: pilots need to be kept informed of how scenarios develop, since their own radars have limited scope and range. WDs give pilots picture calls when the position or heading of a target changes, and sometimes just to reestablish contact. SynTEAM could measure the time elapsed between a change in a target heading and the WD directing his aircraft in response (as mentioned before, constantly changing a target's heading would be one way of keeping a WD tunneled in on a single task). Another idea is to have aircraft request a picture call, either verbally or visually (say, through a change in symbology). This could happen when the WD has ignored its aircraft for a set amount of time or, perhaps, when the WD's aircraft detects another aircraft to which it is not committed. SynTEAM would measure the time elapsed between the aircraft request and the WD's response.
- Compensating for workload: WDs become busy at different times, and in a good team less-busy WDs will step in to help those who are overloaded. SynTEAM could

measure how busy each WD is; based upon the number of tracks under his control, the number of actions issued per unit time and/or the types and amounts of activities of tracks under his control. This ongoing measure of differential workload could be related to other measures of how WDs share tasks or help each other out (see below).

- Sharing tasks and helping: WDs help each other by taking over or monitoring tasks that are not their own. SynTEAM could capture this by looking at the extent to which WDs perform operations on tracks that are not their own, or zoom in on tasks that are not their own. One idea would be to design SynTEAM so that WDs can monitor their own tasks effectively only by zooming in on them. In this case, zooming in on someone else's task (and losing sight of ones own AOR) would unambiguously signal cooperative monitoring and/or work-sharing. Scenarios would have to be designed with WDs assigned to different parts of a campaign geography that was too big to monitor while zoomed out.
- Prioritization: appropriately prioritizing tasks is a major part of the WD job. If tasks are pre-prioritized by experimenters, a measure of how much attention is paid to each task can be compared to this "ideal" prioritization.

In addition to the above broadly conceptual process measures, some simpler smaller-scale generic measures may be informative and easy to record:

- Time taken to respond to various events: heading changes, pilot requests, "spitters" (hostile aircraft breaking away from a dogfight), downed aircraft
- Time taken to respond to messages
- Amount of time a hostile aircraft is left uncovered after it passes a critical point ("commit line")
- Number of times control of aircraft is passed between WDs
- Errors with respect to ROE
- Accuracy of information passed between WDs
- Whether WDs correctly acknowledge messages passed to them
- Whether the SD is advised when something out of the ordinary happens

Most of these measures should be viewed in light of the total amount of activity going on in that time period, so that processes can be tracked in relation to workload. These measures obviously need to be refined: we suggest that the early versions of SynTEAM output a log file of all events and actions that occur during a mission, as does the C^3-STARS simulator. These log files could then be used as raw data from which to construct and refine process measures. Another possibility worth considering for capturing data on the focus of WDs' attention is to add eye-tracking capability. That way, it would be possible to determine where a WD's focus lies independently of whether or not he is zoomed in on an area of the screen.

Finally, a large problem that will have to be overcome is that many of the variables most useful for process measurements may, depending on how SynTEAM is finally implemented, be spoken commands. For example, passing information when needed is a good indicator of an efficient team, and since WDs do this verbally there may be no easy way for the system to capture this (i.e., it may have to be done the hard way - through transcribing the voice data).

CONCLUSIONS

We note that our CTA is obviously not comprehensive. We did not sample all the specific events that could occur in the WD task (and/or describe fully how WDs dealt with the events we did catalog). Nor did we capture all the strategies and tactics used by WDs. To some extent a CTA that approaches this kind of comprehensiveness may only be possible after extensive observation of WDs within an existing synthetic task environment (e.g. a simulator), and then only under a diverse set of scenarios meant to fully elicit their job expertise. Another issue is that while the higher-level strategic decisions were especially important in our characterization of a synthetic WD task, in reality WDs do not ordinarily exercise this authority, deferring to the SD. This represents a limitation on the population we interviewed; however, this population did include some SDs.

The current report does not exhaust our CTA data (or ideas), and there may be other ways to mine the data to further inform SynTEAM implementation decisions. However, our CTA data, as it stands, produced a good general overview of the WD task. Inherent in the summaries of the CTA data we hope to have shown a good starting point for the development of an ecologically valid synthetic AWACS task.

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APPENDICES

Appendix A: Interview Guides

N.B.: In Sections A and E, only those probes written *in italics* are intended to be used verbatim. In Sections B, C, and D, all probes can be used verbatim.

---A: General Interview Guide

1. Ask WD for background information
   - Rank, years in the Air Force.
   - Years as a WD.
   - Experience as an SD?
   - Variety of missions flown.

2. Ask WD to describe the job characteristics and list a WD's main tasks/responsibilities:
   - Emphasis on concrete examples.
   - Which responsibilities/tasks place the highest burden on a WD?
   - Which aspects of the job are cognitively challenging?
     * E.g., tasks that task memory, attention, impose a high workload.
   - Knowledge Audit: What are the main skills of a WD?
     * Past and future projection:
     "Have you ever walked into a situation and known exactly 'what the score was'?"
     * The "big picture" view:
     "What is important about the Big Picture? What do you need to keep track of"?
     * Noticing cues:
     "Have you had experiences where part of a situation 'popped out' at you? Did you notice things others didn't catch? Give an example"
     * Job smarts:
     "Do you use any strategies that allow you to work smart or accomplish more?"
     * Opportunities/improvising:
     "Give an example where you have had to improvise or find a better method."
     * Anomalies:
     "Give examples of when you spotted a deviation from the norm, or knew something was wrong."
     * Equipment difficulties:
     "Are you ever led astray by the equipment? How do you 'trade off' between what the equipment says and your own judgment?"

3. Ask WD to list the different kinds of missions in which he/she may be called upon to participate (e.g., defensive counter air, strike, search and rescue):
   - Give concrete examples of each kind of mission.
     * Doctrine, Rules of Engagement.
   - Discuss the difficulties encountered on each kind of mission.

* Cognitive demands (memory, attention, workload, etc.).
* Number of decisions.
* "Tempo" of mission.
* Degree of teamwork (communication, cooperation).

- Discuss the different strategies used in each type of mission.
  * What are the advantages and disadvantages of each strategy?
  * Degree of teamwork (communication, cooperation).

4. Work through a series of "generic" missions/strategies (defensive counter air, strike, search and rescue):
   - List important decision points, with an emphasis on concrete examples.
   - Discuss the information that feeds into each decision.
     * How is this information obtained (e.g., pattern matching on the screen)?
     * Is it easy to obtain this information?
   - Discuss which decisions require the most teamwork (communication, cooperation).
     * Which decisions that require input from other team members?
     * Of which decisions do other team members need to be notified?
     * How is information shared between team members?
     * What are the impediments to sharing information?
   - How important is shared knowledge?
     * Mental model of the job (degree of overlap).
     * Mental model of the mission (degree of overlap).
     * Situation awareness of the other WDs' situations.
   - Which decisions are most cognitively complex or difficult?
     * What is cognitively complex about it?
     * What cognitive demands are made (perception, memory, etc.)?
   - "Scenario from hell":
     * *"If you were going to devise a scenario to show someone what this job is really about, what would you put in it?"*

5. Discuss current AWACS training:
   - How does training address the needs of the job?
   - How does training prepare WDs for the more demanding aspects of the job?
   - Does the training address teamwork and communication?
   - How could training be improved?

---B: Critical Incident Interview Guide

1. Get critical incident:
   - *"Relate to me an incident that, in your experience, required a lot of teamwork and challenged your/the team's skills."*

2. Have WD construct a timeline of this critical incident (flow of events)

3. Review the timeline with the WD, filling in the gaps and adding other things that come to mind

4. Focusing on events on the timeline, ask about:

- WD's focus of attention:
  - how and why it changed as incident progressed.
  - were changes good or bad?
- cues attended to:
  - determining degree of enemy threat and status of friendly resources.
  - reliance on information in other WDs' lanes, or information from other WDs.
- communication/cooperation with other team members:
  - when and how communication/cooperation took place.
  - was communication/cooperation successful?
  - modes of communication/cooperation.
  - communication that **should** have occurred.
- options considered:
  - reasons for selecting the final course of action.
- resource allocation:
  - why WD selected particular tracks to commit against the enemy.
- loss/deterioration of situation awareness:
  - means of regaining SA.
  - help from other team-members in regaining SA.

---C: Quasi-Performance Interview Guide

The bulleted text represents the actual questions, while the headings in square brackets are meant to remind interviewers of the PARI categories.

Situation Awareness Probes: "What's going on now."

- Give me an overview of what is going on, both in WD2's and the other WDs' lanes.
- What are the current rules of engagement? Explain the rules of engagement.
- What resources does WD2 control? Draw them on the map, along with their HAS*.
- What targets are in WD2's area? Draw them on the map, along with their HAS*.
- What are WD2's resources doing and why?
- How would you prioritize the targets in WD2's lane? Do you think WD2 is prioritizing them differently? How? Why?
- What resources do the other WDs control? Draw them on the map, along with their HAS*.
- What targets are in the other WDs' area? Draw them on the map, along with their HAS*.
- What are the other WDs' resources doing and why?

- Do you think that the situation is under control? Why?
- Talk about how the WDs work as a team. Do they communicate well, etc.?
- What do you think will happen in the next few minutes?

* Be sure to emphasize that we would like the WDs to draw any information on the map, no matter how sketchy (if this is not emphasized they might not draw aircraft unless they remember the position, HAS **AND** the call sign). If interviewee does not at least know details of WD2's assets, they are not "mission ready" and so discreetly switch to a general interview format.

"Next Action" Probes: "Put yourselves into the situation. What would you do?"

[ACTION]

- What would you do in the next minute or so?

[PRECURSOR]

- Why would you perform these actions? What would your goals be?
- What information would influence your decisions? Why?
- Where and how would you get this information? Would you get it from other team-members?
- Would you be influenced by anything going on in the other WDs' lanes?
- Discuss how target priorities and positions (discussed in the last section) would affect what you decided to do.

[RESULTS]

- Project what the results of your actions would be.
- Would your actions impact the other WDs? Would you need to convey information to anyone else as a result of his actions? Who? What? Why? How?

[INTERPRETATION]

- How would your actions change your overall situation model/mission objectives? Would your actions change your prioritization of the targets in WD2's lane (e.g., Tactical Sort)? How?

[ALTERNATIVE ACTIONS]

- Given your current goals/priorities, discuss how you could meet your goals via different courses of action. Include any alternative actions you could take, or different sequences in which actions could be performed.
- Why wouldn't you take these courses of action?

- Discuss how having different information would affect how you would decide to reach your goal. Where would you get this information? Would you get it from other team members?

[ALTERNATIVE PRECURSORS]

- What other goals could you have at this point? Discuss how your goals would have changed if you had prioritized targets differently.
- Why did you choose not to pursue these goals/use this prioritization?
- Discuss how having different information would have affected your goals at this point. Where would you get this information? Would you get it from other team members?

[ALTERNATIVE RESULTS/INTERPRETATION]

- What else could happen as the results of your actions (e.g., if "something goes wrong)? What would this mean?

"Action Taken" Probes: "Answer questions on events that occurred in the last tape segment."

[ACTIONS]

- What (external) events took place in the last tape segment? Please answer in order of importance (Planes shot down, new planes, etc.).
- What actions/decisions did WD2 take?
- Did WD2 receive any information from WD1 or WD3 during the last tape segment? Was this information accurate?
- Did anything else of consequence happen during the last tape segment?

[PRECURSORS]

- Why do you think WD2 performed the actions he did? What goals was he trying to accomplish?
- What information do you think influenced WD2's decisions? Why?
- Where and how did WD2 get this information? Did he get it from other WDs? Was the information he received accurate?
- Do you think that WD2 was influenced by anything going on in the other WDs' lanes?
- Discuss how target priorities and positions might have affected what WD2 did.

[RESULTS]

- What were the results of WD2's actions?
- Did WD2's actions impact the other WDs? Did the WD need to convey information to anyone else as a result of his actions? Who? What? Why? How?

[INTERPRETATION]

- Discuss how actions/events in the last segment might have changed WD2's overall situation model/mission objectives. How? Discuss how you would change your priorities (e.g., Tactical Sort).

[ALTERNATIVE ACTIONS]

- Given WD2's (inferred) goals/priorities, discuss any other actions he could have taken at this point that would have satisfied these goals.
- Why do you think he didn't take these actions?
- Discuss how having different information might have affected which actions WD2 decided to take at this point. Where would he have gotten this information? Would he have gotten it from other team members?
- Did WD2 do all he needed to do? If not, why not?
- How did WD2's actions differ from your planned actions? Did he use different information to make decisions? How? Why?

[ALTERNATIVE PRECURSORS]

- How did WD2's (inferred) goals differ from your goals? Do you think he used different information to set goals/priorities? How? Why?

[ALTERNATIVE RESULTS/INTERPRETATION]

- What else could have happened in the last segment? What would this have meant?

Appendix B: Critical Incidents

Critical incidents are written in the first person, as they were recounted to us. However, in the interests of clarity the raw reports have been paraphrased. Interviewer comments have been omitted from the bodies of the reports, although an interviewer commentary has been added at the end of each incident. Figures are copies of explanatory drawings made by interviewees.

--- 1) A Difficult Air Refueling

This particular day we had three tankers up there, and I was in charge of refueling all the strike aircraft. It was a rainy day and pilots were having trouble with visibility due to the clouds, so I was giving the aircraft more fuel to make sure they could get back. In the middle of refueling the strike package, I received an emergency call from a British Jaguar. He was screaming for fuel. His trouble was made worse because Jaguars don't have radar.

I quickly started calculating which tanker I could vector out to the Jaguar. I needed to check how many aircraft were on each tanker and also the fuel status of each tanker (to ensure that the tanker had enough fuel to get out to the Jaguar, fuel him, and return back to the strike team). Before I had time to decide, one of the tankers, who had been listening to the radio, responded that he could go. This was a big help in making my decision, and it was an advantage that the tanker pilot knew what was going on. I then coordinated with the tanker to help the Jaguar.

The SD didn't get too involved in this situation, because I was constantly thinking ahead and presenting him with a good solution at each stage of the problem. In the end I decided to do a 150/30 rendezvous. That is where you have the tanker and the other aircraft fly toward one another, then as they near each other the tanker does a 150 degree turn and the other aircraft does a 30 degree turn, rolling right in behind the tanker (see Figure E1). The key here is getting the fighter to do the least amount of turning, in order to save fuel.

The main points within this incident were deciding which tanker to use and figuring out how to get the aircraft together with minimal fuel loss, all the while keeping them out of the wrong air space. After the refueling, I pushed the Jaguar back to the Check-in Controller to send him home, and vectored the tanker back to refuel the strike package. While calculating all of that, I still had to manage the refueling with the two other tankers: first, I would make sure that the intercept between the Jaguar and the tanker was going well (emergencies are always top priority), while still monitoring the other tankers.

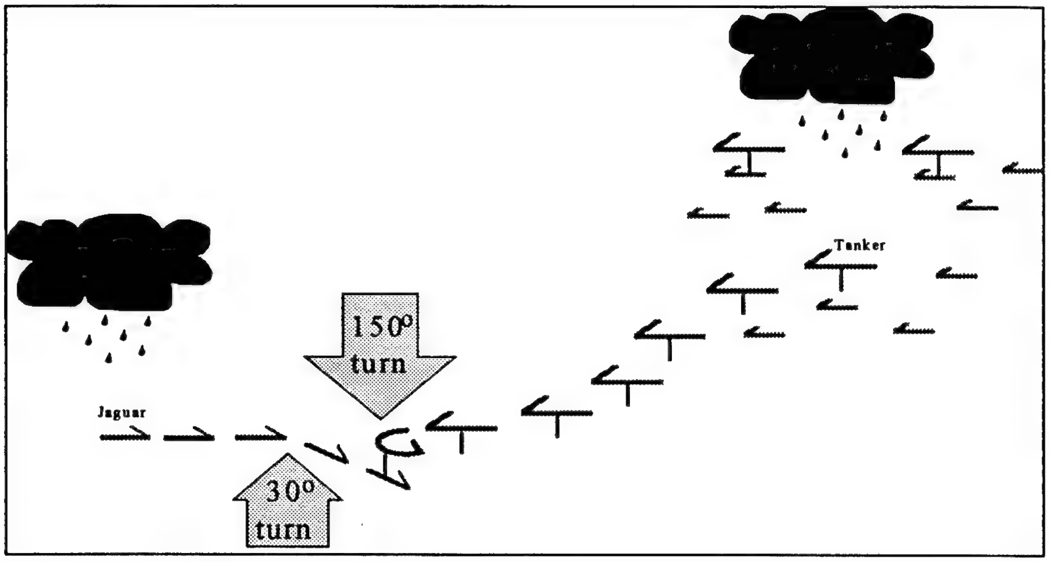

Figure E1: A 150/30 Rendezvous

Commentary

Weather was a major factor here. The Jaguar had used a lot of fuel flying around looking for clear spaces in the clouds, which is what had gotten him into trouble. The WD suddenly had to decide which tanker to use, requiring him to check each tanker's refueling schedule and try to form an impromptu solution while still monitoring the other refuelings taking place. Since the WD was controlling refueling of a large strike team on three tankers, this was not easy. Fortunately, he received help from the tanker pilot, who was listening to the chatter on the tanker frequency. The tanker pilot came up with his own solution, considerably reducing the burden on the WD. Once the WD decided to go with the tanker pilot's plan, he had to calculate some very complex and precise vectoring geometry while still overseeing the refueling on the other two tankers. This required him to switch rapidly between two scope views in order to keep track of all that was going on. This incident highlights how WDs have to form rapid solutions to ambiguous problems, deal with more than one task at one time, and shows how communication between the WDs and pilots can expedite a solution.

--- 2) A Potential "Friendly Fire" Incident with a Helicopter

This is not an elaborate example, but it scared me. I was controlling some fighters patrolling an friendly airspace next to hostile territory (see Figure E2). I was the AOR controller in this mission. The weather was bad and the visibility wasn't very good, so a lot of the aircraft were flying in and out of the clouds trying to get above them. That makes our job a lot harder, because the aircraft often get lost out there and need our help. There was a UN helicopter scheduled to fly across the friendly territory into the hostile territory (above the dotted horizontal line in Figure E2). We knew exactly who he was, and we had his flight plan. He took off and was flying across the "No Fly" zone. At about the same time, we picked up an "unknown" track in the hostile airspace. I personally did not see him, because I was talking to the F15s, and it was also my job to track the UN

helicopter. Tracking helicopters is a tough job, because they are low and slow and often drop off the scope. I heard about the unknown from one of the other WDs, who pointed to it on my scope.

The unknown worried me, so I committed two F-15s (on the left of Figure E2) to check it out. As the F-15s were on their way toward the unknown, the unknown turned away and headed back north. I did not notice this, though. The F-15s locked on to the helicopter instead of the unknown, because it was in the area where the unknown was projected to be, and the weather was bad. Things happened real fast. One of the WDs yelled at me, "He (the bad guy) turned north, pull them (F15s) off!", which I did.

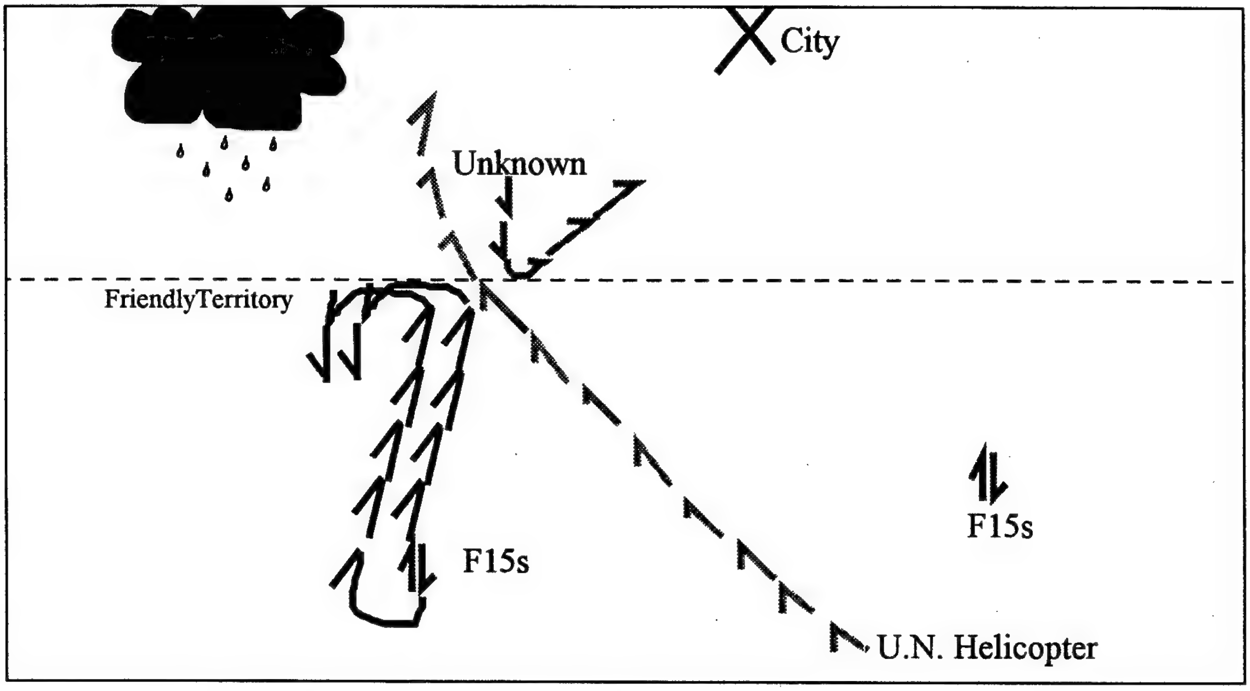

Figure E2. Potential friendly fire with a helicopter.

The bad weather was a major factor in this incident: the F-15 pilots didn't like not being able to actually *see* what they were committed on, so they got too close to the helicopter. This was a big potential problem. Afterwards, we concluded that the unknown was probably either an enemy helicopter or fighter that had come down to investigate the UN helicopter. They knew that the UN helicopter was coming, so they wouldn't have shot it down.

This incident is a good example of my team helping me out. I was so "tunneled in" on the helicopter and the F-15s that I completely missed the unknown. The other WDs helped out with tracking and giving updates on the unknown. In this case, we had proper mission planning and had flown together a lot, so that helped.

Commentary

Again, bad weather was a factor. The WD was quite overloaded, monitoring three tracks (two sets of F-15s and a helicopter) in different areas of the scope. Helicopters are notoriously difficult to track, since they fly low and slowly, often disappearing from radar. The WD became "tunneled in" on the F-15s he had committed, and he did not see that the unknown had turned (and he also forgot about the helicopter). This incident shows how WDs can become overloaded when they have to perform too many tasks, especially in different parts of the scope, requiring frequent scope adjustment, and when one of the tasks (tracking the helicopter) has to be done with imperfect information. It highlights the importance of WDs having a common situation model: the other WD was able both to tell the protagonist that there was a hostile aircraft in the area, and to help when he became tunneled in and did not notice that the hostile had turned away and that the F-15s were in fact locked on to the helicopter.

--- 3) A Potential "Friendly Fire" Incident with Fighters

I was the AOR controller in this incident, in the middle seat, and there was a HVA Controller and a Check-in Controller. A Canadian EF1-11 came off his tanker, and didn't check in with us when he came back into the "box" (the AOR), so we didn't know he was there. All of a sudden, some of our F-16s said "contact", meaning that they'd picked up something on their radars, and giving bearing and range off their noses - that is, relative to their own aircraft. However, I saw nothing on the radar screen in the area that they were indicating. I asked the HVA Controller if he had anything on his scope, in case my scope was malfunctioning. He also saw nothing on his scope. Meanwhile, the F-16s were getting more agitated as they closed in. The SD came over and was looking over my shoulder. I asked the F-16s to give me the bearing and range of the target relative to the bullseye, to get a non-egocentric frame of reference, but they continued to give bearing and range off their noses. The SD wanted to follow the ROE and get a VIS ID (Visual Identification). The F-16s were closing in fast, but finally they visually identified some EF1-11s. The HVA Controller had thought that the EF1-11s were still on tanker, so he checked with the tanker and found out that this was not the case. It must have come off the tanker and had not checked in with us. He let me know, and I called off the F-16s, just in time.

If the F-16 pilots had given contact off the bullseye, the EF1-11s would have heard it and realized that they were in danger. People weren't communicating well. After the incident we had a big briefing on the ground with the fighter pilots, telling the F16s that they needed to follow requests, and the EF1-11s that they needed to check in when they came back in the box.

Commentary

There was a major problem with information here - the target onto which the fighters locked was not on the WD's scope, so the WD was working with limited information, under time pressure. The incident shows how a number of small miscommunications - the EF1-11s not checking back into the box, the refusal to cooperate

on the part of the F-16 pilots - can compound into a major problem. However, the incident also shows how communication between WDs can expedite a solution: the AOR WD was able to concentrate on the fighters while the HVA WD communicated with the tankers to get the necessary information.

--- 4) A Critical Incident Related to the "Black Hawk Shoot Down"

In this mission, we encountered a helicopter that wasn't on the ATO. The ATO is a break-down of all the aircraft that are going to be up that day, including their schedules, and the modes and codes that they will be transmitting. We need to know all this information, because we are the command and control platform for that area. The ATO procedures are set and we follow them exactly.

However, helicopter pilots tend not to follow the ATO. Helicopters are often owned by the Army, and there is a big disconnect between the Air Force and the Army. For example, we would have helicopters take off from Zakho, and some would check in, but some wouldn't. Sometimes they would squawk Mode 4, sometimes they wouldn't; rarely would they have the right Mode 1, which is a big ID code for us on the AWACS. If they did check up they would say, for example, "This is Black Hawk 21 inbound to Arbil," and that was all we would hear from them. The big thing is that we knew who the helicopters were, we just didn't know how they fit into the game plan, and we really do need to know this. In this incident, we were able to the recognize the helicopter problem from the outset, probably because we had more experience going in, and we had developed some pretty good procedures for following helicopters.

The AWACS has a hard time tracking helicopters because they are low and slow: you may pick them up every now and then, but sometimes cannot. You primarily have to track them off of IFF, not radar. It is very easy for symbology to drift off the radar return. These guys usually only check up once, if they bother to check up at all, and it is easy to forget about them. If we don't expect someone up there, or the helicopter is not on the ATO, he is forgotten.

The In-Route Controller picked up a helicopter on the radio. The helicopter identified itself, but used a call sign that was not on the ATO or the Master ATO. However, based on where it was coming from, we guessed it was an Army helicopter. If the In-Route Controller has experience, or is briefed that such an incident may happen, he will tag him up. However, in this incident the In-Route Controller had no idea where to look. We (the other WDs) were not doing anything, so we were helping him. The In-Route Controller didn't know where the Army base was, so I reached over and pointed on his scope. He started tracking, but only got intermittent blips on the scope. He tracked him to the box, at which point the helicopter should have checked in and got put on the AOR frequency. However, he didn't check in, and so did not get put on the AOR frequency. My F-15s came in and swept the area. They were not expecting anyone in the area, but they picked up on a helicopter out there. I knew that there were friendly helicopters in the area, but we didn't know what the Army was doing out there. The F-15s moved in, locked on to the helicopter, and radioed to us. I could not see the helicopter, so I asked the In-Route

Controller if he knew where the helicopter he was tracking was. At that point, the In-Route Controller noticed that the helicopter had passed Gate One going into the box and needed to be put on the AOR frequency. That is frequency coordination. If no one had caught this, the helicopter would have stayed on the In-Route Controller's frequency until he reached his destination. This would have been a bad thing, because I was controlling all the fighters out there, not the In-Route Controller, and I wouldn't have been able to contact the helicopter on my frequency, so I wouldn't have known who he was.

Commentary

Again, this incident was based on miscommunication, not so much between the WDs but more between the helicopter pilots and the WDs. The In-Route controller was working with imperfect information: the same problem with helicopters periodically dropping from the radar. Coordination between the WDs saved this from becoming a major incident: if WDs didn't have the same mental/situation model, they would not have picked up on the In-Route controller's error of not putting the helicopter on the AOR frequency.

--- 5) Refueling the E3 AWACS Aircraft

One time the E3 was refueling, which means that the radar was shut down and "other agencies" were controlling the aircraft that were up (including us). When our radar came back up, the ASO did a diagnostics on the equipment and declared the radar operational, as usually happens. Once we're back online we're responsible for the area. However, all of a sudden we were faced with 6 hostile aircraft flying, and we had no other aircraft up. In this case we had no option but to turn and run. The MCC got on the radio, but the hostiles all landed soon after, so nothing happened. If there had been assets airborne and they were being controlled by the other agency, we would have coordinated with that agency to take over, maybe wait for a lull in the action. The SD usually does the coordination with the other agencies. The general feeling was that the AWACS schedule was getting too predictable, and we needed to change this in order to not be so vulnerable.

Commentary

The main point of this incident is that the WD environment is both dynamic and uncertain: the WDs were thrown into a situation where things were suddenly different from before, and they had to work together quickly to address the new situation.

--- 6) A Stateside Incident: Large Force Exercise in Utah

The day of the incident I was controlling 2 F4s flying together. One of my F4s lost an engine, but did not tell me that he was in trouble. I had to infer what was going on. The pilot said, "stand by one, can you get the wing man over?" As soon as he said that I recognized, from experience, that something was up. So I vectored the wing-man over and informed the SD that I thought something was wrong. The wing-man went over there and checked out the plane for structural damage, and relayed to the pilot that he had lost

only one engine: the other was still operational, so he could fly. However, the loss of an engine means a loss in maneuverability, and he was also low on fuel. The WD sitting next to me picked up on the situation, and took over talking to ATC to help out so I could then just talk to the pilot. We had to work together: it was three-way teamwork between myself, the controller next to me, and the SD to get pilot back to base.

The key to any emergency is to listen, because you want to hear the pilot going down his check list, trying to figure out what is wrong. You don't want to be talking on the radio and interrupting his thoughts when assessing the situation. If there is something that I need that the pilot is not giving me, then I would ask. The center WD was helping me pick up information from what the pilot was saying to me, then passing that information on to ATC so they could be prepared handle the incoming emergency.

Commentary

This incident emphasizes the importance of communication and teamwork. Even though the WD was not directly communicating with the pilot, the fact that the WD could hear the pilot doing his checklist was obviously a great help here. The fact that the WD was able to quickly and easily pass off the task of coordinating with ATC to another WD greatly helped him to concentrate on the task at hand.

--- 7) A "Downed" Aircraft

Once, while controlling over Michigan, ATC told us that a military aircraft had gone down. All WDs immediately counted their own aircraft. All WDs were experienced. The SD said to stop whatever we were doing, and all planes went to CAP. I became the coordinator between ATC and the WDs, known as a "pit boss". The SD was doing the actual coordination, I was relaying information to the WDs, like a 2nd SD. We used our own aircraft, and sent some F16s to look over the exact area. We saw nothing, but continued to look. The fighters were eventually sent home, although we stayed out. The SD did a lot of coordination with the ground. Finally, all was explained and we went home: a C130 had gone low over a ridge, and a witness had thought it had crashed.

Commentary

This incident illustrates how new situations can quickly unfold, and how WDs sometimes need to coordinate and reconfigure their teams quickly to deal with new problems.